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# AN EVALUATION OF THE ARTS (AUTOMATED RADAR TERMINAL SYSTEM) III LEVEL OF AUTOMATION (THIRD LOT PROCUREMENT)

Seymour M. Horowitz

Federal Aviation Administration
Washington, D. C.

July 1972

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FINAL REPORT

# AN EVALUATION OF THE ARTS III LEVEL OF AUTOMATION

(Third Lot Procurement)



July 1972



Seymour M. Horowitz

DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
Office of Aviation Economics
Economic Analysis Division

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15. Supplementary Notes

The experimental work which formed the basis for this evaluation was performed at the National Aviation Facilities Experimental Center (NAFEC).

16. Abstract

An evaluation of a new Automated Radar Terminal System (ARTS III) for controlling air traffic was made by simulating the air traffic environment in a statistically balanced experimental setting. Similar groups of air traffic controllers using both the ARTS III and the older system were presented with identical traffic patterns. A large number of measures of system performance were taken. Differences favoring the ARTS system were found in the most critical of these measures, Safety, and were translated into dollar benefits resulting from an expected reduction in mid-air collisions. A comparison of these dollar benefits with the incremental costs to install and operate the new equipment favored its installation.

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## EXECUTIVE PRECIS

An experiment using FAA air traffic controllers in an environment designed to be typical of low density airport terminals was conducted at NAFEC during March 1971. This setting was used in order to compare the ARTS III level of terminal automation with the present "manual" system. A wide range of important indicators of air traffic control performance was used in this comparison intended as part of the evaluation of the decision to exercise the option to purchase the remaining (third) lot of ARTS III equipment; 64 installation sites were specified in the initial contract, 29 sites remained in the third lot option. In separate simulated experiments, both certificated and trainee controllers were presented with identical traffic samples in a statistically controlled environment. The important findings were:

1) There was a statistically significant reduction in communications workloads due to ARTS III.

2) There was a statistically significant reduction in the time that IFR and VFR aircraft were in violation of minimum air spacing standards (conflicts) due to ARTS III.

There was an indicated reduction in conflicts between IFR aircraft due to ARTS III.

3) There were no reductions in the time in system or increases in the number of aircraft handled that can be claimed for ARTS at the level of automation and with the terminal geometry employed in this study.

4) There were no statistically significant differences between the trainee and certificated controller groups in the categories of time in system and numbers of aircraft handled. However, the trainee group using ARTS III showed a statistically significant reduction in the numbers of conflicts involving IFR aircraft. The measurements for safety for the trainee controller using ARTS was generally comparable to the certificated controller using ARTS. The performance of the trainee group in separating IFR traffic with the manual system was totally unsatisfactory.

5) Follow-on analyses of the conflict data were performed in an attempt to isolate those specific features of ARTS III automation that contribute significantly to the observed reduction in conflicts. These analyses tend to show that Mode C or altitude information was an important contributor, but this conclusion cannot be verified with a high degree of statistical confidence.

Dollar savings in operating costs were claimed for ARTS III due to reductions in training required for controller certification. These savings are not appreciable, however, and do not affect the study's results or conclusions. No dollar savings in costs were claimed due to reductions in communications workload.

The dollar benefits likely to result from a reduction in midair collisions, based upon the study's findings of statistically significant differences in the time in conflict for IFR x VFR aircraft, were estimated for a wide range of expected number of midair collisions and for a similar range of values for the cost of an accident.

The study concludes that the installation of ARTS III equipment is justified for all locations involved in the third lot procurement on the basis of using conservative estimates, the low end of the range, for the number and dollar costs of midair collisions that are expected to occur in the next decade.

TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF TABLES (Cont'd)



## LIST OF FIGURES

## SUMMARY

An experiment employing air traffic controllers from the Federal Aviation Administration in a realistic, but simulated, terminal environment was conducted at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey, during March 1971. Its purpose was to aid in deciding whether an option to buy 2[illegible] systems of automated equipment -- designated as ARTS III -- should be exercised. A contract existed with the Univac Corporation to purchase a total of 64 ARTS III systems under three separate option agreements for installation at major air terminals. The options to buy lots one and two, to be installed at the busier terminals, had already been exercised.

A simple terminal geometry, typical of the less busy terminal locations included in the third lot option, was devised as the appropriate setting in which to compare the ARTS III level of automation with the present, so-called "manual" system. In isolated experiments, certificated and trainee controllers were presented with identical traffic samples under statistically controlled conditions. Detailed measurements of comparative system performance -- some 80 specific indices in seven major categories -- were taken. All measurements taken during the run of the experiment are shown in Section I of this report, unedited, along with estimates of those statistical measures thought to be most relevant to the evaluation of significant differences between systems. The statistical analyses of these indices of performance, designated to be measured prior to the running of the experiment revealed the following general results:

1) There was a statistically significant reduction, due to ARTS III, in the performance category of Communications Workload.

2) There was a significant improvement in the category of Safety, due to ARTS III, as measured by the violations of minimum spacing standards (conflicts). Conflicts between aircraft receiving navigational assistance as well as a traffic advisory service from the FAA (those operating under Instrument Flight Rules, IFR) interacting with aircraft not under FAA control (those operating under Visual Flight Rules, VFR) were reduced to a statistically significant degree. Conflicts between IFR aircraft were reduced to an indicated, though not statistically significant, degree using ARTS III.

3) There was no reduction in the category of Time in the Terminal Area, and no increase in the Numbers of Aircraft Handled demonstrated by ARTS equipment at the level of automation and for the terminal geometry employed in this study.

4) There were no differences between the trainee and certificated controller groups in the categories described above in item 3: Time in the Terminal Area; Numbers of Aircraft Handled. The total performance of the trainee group, using ARTS III equipment, was generally comparable to that of the certificated group. However, the ability of the trainee controller to avoid conflicts was highly unsatisfactory when using the present manual system of control. This latter finding indicated the possibility for deriving dollar benefits from the reduction in the period of training required for controller certification. This

possibility, uncovered in an experiment using simulated conditions, has been verified by recent accounts of the experience in training controllers in the use of ARTS equipment reported by the Atlanta terminal facility.

The general theme suggested by the above findings is that ARTS III equipment provides improved system performance in the most critical of areas; safety. Based upon these experimental findings it was postulated that a major factor contributing to the ability to control traffic safely with fewer conflicts is the increased availability of information in three dimensions concerning the location of all aircraft within the terminal area. Aircraft for which spatial information in the x, y and z coordinates is available are defined as "known" to the system. All IFR aircraft meet this definition. The radar contact provides spatial information to the ground controller in two dimensions. Radio communication with the pilot confirms the third dimension, the aircraft's altitude. Therefore, under the present manual system, information in three dimensions is as recent as the last radio contact. For the ARTS system, this information is updated to be as recent as the last radar sweep, if the aircraft is equipped with a beacon transponder with Mode C capability (i.e., the capability to transmit altitude information automatically, in response to an interrogation by a ground based radar beacon). More importantly, according to the definition adopted -- aircraft for which spatial information in all three dimensions is lacking are regarded as "unknowns" -- all VFR aircraft are unknown

to the present system of terminal control, whereas that portion of the VFR traffic equipped with Mode C transformers are known to the ARTS system. It is this latter feature of control that the study postulates to be the discriminating element in the observed reduction in conflicts, although other desirable features of control available from the ARTS may have contributed as well. An extensive analysis of the experimental data was undertaken to investigate whether it was possible to specifically identify the features included in the package of automation available from ARTS III that contributed most importantly to improved system performance. This analysis was designed to answer the questions: 1) were the data on the target's ground speed, displayed automatically on the ARTS radar display, important to the controller; 2) was altitude information important; and 3) did the mere "freshness" of the data contribute to the controller's performance? The answers to these questions would help immeasurably in defining the requirements for future installations of automated equipment.

An operational analysis of the data was performed, after the experiment, by NAFEC personnel experienced in the methods and procedures of air traffic control. In addition, The MITRE Corporation and the Transportation Systems Center of the Department of Transportation performed separate statistical analyses designed to isolate those automation features which proved to be most beneficial to the controller. The results of these follow-on analyses are contained in Appendix A to this report. A summary description of these post-experiment analyses and their findings follow:

1) The operational analysis which was performed by NAFEC applied judgmental factors based upon experience in order to weight the number of conflicts by their degree of severity. The result was that conflicts, adjusted for seriousness of the violation, were determined to be less severe, in both horizontal and vertical directions, for the NAFEC certificated controller and the trainee controller using ARTS. But, it was not possible to specifically identify the automation feature contributing most significantly to this result.

2) The MITRE Corporation conducted statistical regression analyses of the experimental data designed to determine a pattern for the number of conflicts occurring on a controller's radar scope at any specified instant of time. Sample measurements of conflict information were taken at one minute intervals. The analysis of these conflict measurements, which included a consideration of the degree of seriousness of the violation, revealed that the number of unknown targets on the scope are a statistically significant explanatory variable of the reduced numbers of conflicts observed for the ARTS system. This confirms the position held prior to the conduct of the experiment. However, the analysis also revealed that the factors which influence conflicts are so numerous and diverse that it is not possible to conclude on the basis of these data that any single feature of ARTS III, such as Mode C or altitude capability, contributed in an appreciable way to the observed reduction in conflicts.

3) The Transportation Systems Center was assigned the task of performing some additional, more analytically sophisticated, statistical tests to determine the contribution to improved safety made by the addition of airborne transponders with Mode C capability. The idea here was to determine whether these aircraft which are involved in violations of airspace standards are affected significantly by the fact that they were equipped with airborne transponders having Mode C capability. This is in contrast to the previous analysis which determined that transponder equipped aircraft reduced system conflicts in general, but which did not attempt to determine whether they were reduced for those specific aircraft involved in the violation. Unfortunately, both the traffic samples and the design of the experiment conducted at NAFEC did not allow for this kind of extended statistical treatment. The only conclusion possible is that any effect that transponders with Mode C might have in keeping aircraft having this equipment out of conflicts, cannot be confirmed with high reliability by the experiment recently conducted. It is hoped that this effect will be reinvestigated in a future experiment more appropriately designed to answer this specific question.

The results of the experiment -- all the data collected, expressed in their physical units of measurement -- are shown in Section I of the study. An interpretative Section II, which assesses the validity of applying these results from a simulated experiment to real-world problems, follows.

An estimate of the dollar benefits likely to result from the installation of ARTS equipment is shown in Section III. Since it is not possible to remove all of the subjective judgment that is necessary to perform these analyses, the array of assumptions and inferences used to obtain dollar estimates of the benefits to be derived from ARTS III equipment are identified explicitly in this section in order that the reader might, at least, confirm the estimates.

One of the pitfalls of cost/benefit analyses is that dollar benefits are frequently double-counted, and more. However, it is usually possible, when dealing with multidimensional indices, to translate changes in one dimension of performance into any of the others. For example, a reduction in the safety dimension -- conflicts -- may be translated into 1) a reduction in delays by asking the question: "For the same number of conflicts, how much longer would it take aircraft to arrive or depart from a terminal using a manual system of control," or into 2) an increase in controller capacity by rephrasing the question to determine the increased numbers of aircraft that could be handled for any identical number of conflicts. Similarly, the reductions in communications workload, which was demonstrated to be significantly lower for ARTS III controllers at very high levels of statistical confidence, could be translated into a quantitative measure of the probability that any given communication channel would be congested. This probability could then be re-translated into a probability of reduced conflicts. But, it is clearly in error to compute benefits by summing up the separate dollar estimates for 1) Safety, 2) Delays,

3) Capacity, and 4) Communications Workload when it is evident that these seemingly different dimensions of performance are not mutually exclusive. However, there is one dimension to the job of controlling aircraft that dominates all the others, Safety. For this reason, the dollar amounts of benefits attributable to ARTS III, shown in Section II, are based primarily upon this single, but critical, dimension of the job. Dollar benefits due to increased safety were based upon the observed experimental finding -- index 54 -- that there is a statistically significant difference in the time in conflict in the terminal area between known aircraft (IFR) and unknown aircraft (VFR) due to ARTS III. This experimental finding of a significant reduction in the time spent in conflict was translated into a reduced probability of a midair collision. Other experimental findings, such as statistically significant reductions in a wide category of measures for communications workload were not translated into dollar benefits for ARTS III, but were assumed to be complementary influences contributing to the observed reduction in Index 54, the time in conflict. Therefore, except for a small dollar benefit attributed to the experimentally observed, and empirically verified, ability of ARTS III to reduce the time required to train an apprentice controller, all dollar benefits are based on the single job dimension of safety. Every attempt was made to eliminate any redundancy in dollar benefits claimed for ARTS III.

The dollar amounts of benefits shown in Section II were estimated for a wide range of assumptions regarding the types of aircraft likely

to be involved in a midair collision, and for a similar wide range of values assumed for the costs of these accidents. The range of possibilities for midair accidents included a consideration of collisions between small general aviation aircraft with single occupants earning low incomes to an alternative consideration of a collision between jumbo jets full of passengers earning high incomes.

The study concludes that the installation of ARTS III equipment is justified at all locations named in the third lot procurement of ARTS III even when the low end of the range -- small aircraft with single occupants earning low incomes -- are assumed to be typical of the midair collisions likely to occur in the next decade.

## CANDIDATE SYSTEMS FOR CONTROL IN TERMINAL AREAS

Terminal traffic consists of aircraft operating in the terminal area under either instrument or visual flight rules (IFR or VFR). Air traffic control advisories -- navigational assistance plus separation service - are provided for all IFR traffic out to a distance of some 40 miles, depending on location.

### 1. The Manual System

Control of aircraft entering or departing the terminal airspace requires that each aircraft be identified precisely. Detailed information regarding an aircraft's position, altitude and speed presently require substantial verbal communications: 1) controller/pilot communication is required to update an aircraft's three-dimensional position and to respond to control advisories; 2) terminal controllers communicate with en route controllers and among themselves in order to transfer information and carry out handoffs of control. For the most part, terminal controllers must maintain a mental picture of aircraft under their control by observing unmarked target reflections on a radar display, aided by flight progress strips on which pertinent aircraft information is recorded. The present equipment has no capability to display a computer generated data block adjacent to a radar target. All targets appearing on the radar scope must be identified by other means. Limited target identification is available, however, at those terminals scheduled to receive ARTS III equipment in the third lot buy. These locations all have wide band radars and beacon decoding equipment

capable of representing targets by a single slash if a primary radar return is received, and by a double parallel slash if a secondary return is received from an aircraft's beacon transponder. The essential element is that the correlation between the beacon slashes displayed and the aircraft target's identity and altitude must be performed manually by referring to a set of flight progress strips stacked adjacent to the radar display.

2. The ARTS III System

ARTS III is a system of airborne and ground components, used in conjunction with existing radar equipment, capable of automatically displaying information required for the control of air traffic. This information is displayed on a controller's radar scope in the form of a block of data tagged to each target. The airborne component of the system is a beacon transponder that transmits a signal in response to an interrogation from a ground based radar beacon. This interrogation is made at each sweep of the terminal's surveillance radar; a secondary radar antenna is attached to the primary antenna for the purpose of transmitting and receiving these signals. The aircraft's beacon response is processed by a ground component which decodes the signal into a digitized electronic impulse that can be represented by a numerical display on a radar scope. A target can, thus, be identified and tracked continually at each sweep of the radar's antenna; i.e., every four seconds. The quantity and kinds of information that are displayed depend to a large extent on the amount of information that is transmitted

by the aircraft's transponder. If this transponder is an older type capable of transmitting only 64 discrete digital messages, then the ability to positively identif an aircraft target is, of course, limited to this number of codes. There is a clear possibility of misidentification of targets. However, the newer and more prevalent type of transponder is not only equipped with the capability for more discrete codes, a total of 4096, but they are also capable of transmitting a signal which contains information regarding the target's altitude. A transponder which provides information sufficient for identification and tracking is designated as having Mode A capability; a transponder which transmits an altitude signal is designated as having Mode C capability. The ARTS III equipment is designed, primarily, to be used with the newer 4096 code transponder with Mode C capability, although the older type of transponder with 64 discrete codes can be accommodated and provided with a reduced number of automated features.

An essential component of the ARTS III system is a ground based computer. It is this component that provides the additional levels of automation that distinguish the ARTS III system from less sophisticated and less useful systems of control. Beacon decoding equipment without computer assistance is able to display the identifying code of an aircraft's transponder in numerical form only. But, this is not the form that is used in controlling traffic or in transferring this control from the en route center to the terminal, or between terminal sectors.

Targets are typically identified and controlled by an alphanumeric designation. For example, a United Air Lines flight number 342 is presently written as UA 342 on the plastic strips or "shrimp boats" which are moved manually across the radar scope as a flight progresses. Handoffs or transfers of control are, likewise, designated by an alphanumeric indication of an aircraft's flight number. Less sophisticated, non-computerized, systems are capable of attaching a numerical data block only, e.g., #6349 rather than UA 342, to a radar target. However, this tag could prove confusing to a controller who must continually make the mental correlation between a transponder code and a flight number.

The use of stored computer memory is an efficient method for assisting the controller in making the association, without error, between radar targets and the alphanumeric data needed for their control. However, once a computer is installed for this purpose, there are additional features that can be derived from the computer's ability to repeatedly perform logical calculations that enhance the controller's ability to handle air traffic. For example, the controller can observe a target move along his radar display and gauge its speed under the present system of control, by experience. But, this task becomes more difficult if many targets are being worked and the controller's attention is diverted. On the other hand, a computer can record the time it takes an aircraft to move between any two points -- the geography of a given terminal is stored in its memory -- and it can display the ground

speed of an airborne target directly upon the radar scope. Similarly, the computer can use a stored program of mathematical alogarithms to anticipate a target's future track. Missed signals or signals which are equivocal, due to reflections or ghosts, can be resolved and a data block assigned to the appropriate target within any order of statistical reliability. The additional automated features available from a computer software program has evolved from considerable experience with prototype installations at the New York City Common IFR Facility and at the Atlanta, Georgia, facility. The automated equipment at New York, called ARTS IA, was commissioned in June 1969; the facility in Atlanta, called ARTS I, became fully operational in September 1966. The list of ARTS III features, shown below in Table I, are currently in use at these facilities, but both New York and Atlanta terminals also have the capability to track targets based upon a response received from interrogation by the primary radar. It is expected that the ability to track primary radar returns will be added to the present ARTS III equipment in follow-on updating of this equipment. In addition, it is expected that such further automated features as computer assisted sequencing and spacing of arrival aircraft will also be added to current ARTS III capability. The use of ARTS III as a platform for future levels of automation is an important element in its design. ARTS III is designed to be modular: increased computer memory can be added in discrete, modular, units either as traffic levels increase or more automated features are desired. Despite these "platform" benefits, the present study is limited to a study of ARTS III for ARTS III

sake only. No attempt has been made to simulate any of the follow-on features of automation, or to impute benefits from them. Instead, the study attempted to construct the most realistic representation of the following list of ARTS III features at its NAFEC facility and to limit its appraisal to these features only.

### Table I

### MAJOR FUNCTIONS OF ARTS III

- The automatic placement of data tag information -- 1) alphanumeric identity; 2) ground speed; and 3) altitude if target has Mode C.
- Automatic initiation and display for discrete coded transponder targets on takeoff; no keyboard entry is necessary.
- Interfacility handoff capability which transfers alphanumeric tags between the terminal and the adjacent en route ARTC Center equipped Stage A automation of the National Airspace System.
- Intrafacility handoff capability which transfers tags from one operating position to another within the terminal.
- Quick-look capability which permits one position to look at alphanumerics displayed at another position.
- Automatic track drop which will eliminate the tags at a predetermined range and/or altitude.

In addition, keyboard controls enable the controller to eliminate fields in the tag, manually drop tracks and otherwise tailor the physical

presentation (intensity of targets -- alphanumerics, operating range and offset) to his particular requirements.

- Flight emergencies

A special emergency code is inserted over the alphanumeric tag of any flight which develops an emergency. This code appears on all controller radar displays in the facility and an audible signal is activated to alert all controllers. One control position is then assigned to work with the distressed aircraft until the emergency is resolved.

A typical ARTS III display is shown in Figure 1. The manual system can be described as a similar display in which no data block is attached to the radar target shown. The writing of relevant information required for the control of air traffic directly on the radar display is the essential element of ARTS level of automation. The study's purpose is to determine whether the automatic tracking and radar scope display of this information is sufficiently beneficial to justify the installation of ARTS III equipment at those terminal locations identified in the third lot option.

## ARTS III Candidate Locations

Table 2 identifies the terminals included in the third lot option to buy. The itinerant operations for FY 1970 at the primary airports scheduled for ARTS III installations are also shown in this table. These numbers of operations were a major part of the criteria used to select the ARTS III candidate locations. However, as a result of this study,

# TYPICAL ARTS III DISPLAY

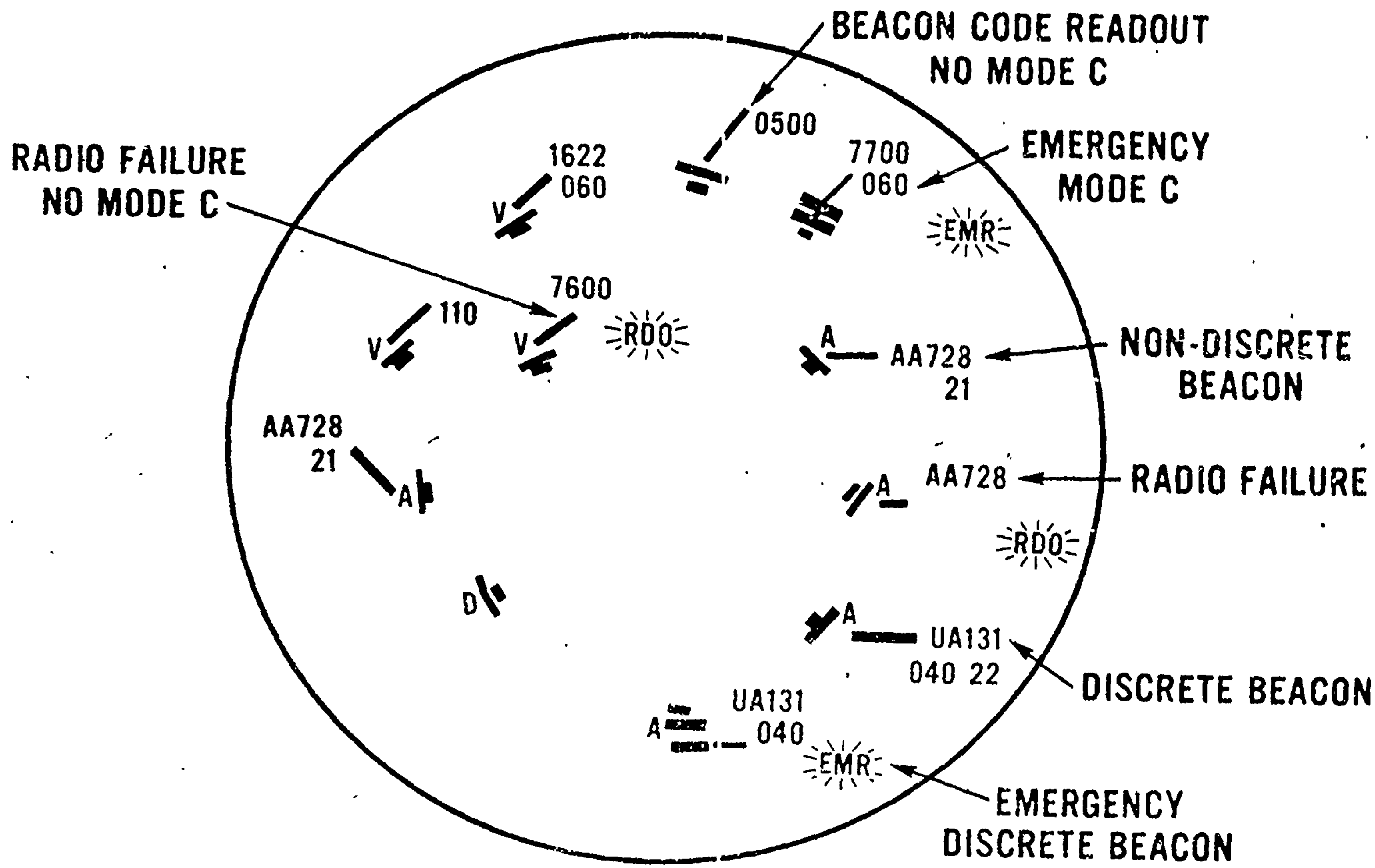



Figure 1

Table 2

AIRCRAFT OPERATIONS AT AIRPORTS
PROPOSED FOR THE THIRD LOT PROCUREMENT, ARTS III
FY 1970

(In Thousands)

| Airport | Itinerant Operations* | | | | Local | Total |
|---|---|---|---|---|---|---|
| | Air Carrier | General Aviation | Military | Sum, Itinerant | | |
| Tampa | 83.0 | 61.7 | 0.7 | 145.4 | 12.8 | 158.2 |
| Baltimore | 131.2 | 93.5 | 2.4 | 227.1 | 11.4 | 238.5 |
| Portland, Oregon | 91.5 | 59.2 | 14.5 | 165.2 | 17.3 | 182.5 |
| Orlando | -- | 136.9 | 2.0 | 138.9 | 57.7 | 196.6 |
| Dayton | 59.5 | 97.8 | 0.3 | 157.6 | 44.6 | 202.1 |
| Omaha | 46.8 | 95.0 | 1.6 | 143.3 | 90.1 | 233.4 |
| Nashville | 63.9 | 86.2 | 7.6 | 157.7 | 51.1 | 208.8 |
| Jacksonville | 49.1 | 30.6 | 11.2 | 90.9 | 13.1 | 104.0 |
| Louisville (Stand) | 83.3 | 41.3 | 8.0 | 132.6 | 14.0 | 146.6 |
| Birmingham | 48.1 | 87.4 | 17.1 | 152.6 | 78.9 | 231.5 |
| Hartford (Windsor Locks) | 60.2 | 66.5 | 7.1 | 133.8 | 21.7 | 155.5 |
| Salt Lake City | 68.1 | 125.5 | 9.9 | 203.5 | 89.9 | 293.4 |
| Rochester, N.Y. | 61.3 | 69.5 | 1.3 | 132.0 | 102.4 | 234.4 |
| Syracuse | 61.3 | 49.8 | 9.7 | 120.8 | 29.9 | 150.7 |
| Tulsa (Int'l) | 48.5 | 109.8 | 7.0 | 165.4 | 45.2 | 210.6 |
| Albuquerque | 46.1 | 98.4 | 29.6 | 174.1 | 39.2 | 213.2 |
| Providence, R.I. | 54.8 | 71.7 | 9.6 | 136.1 | 65.3 | 201.5 |
| El Paso | 38.2 | 95.3 | 22.3 | 155.9 | 84.1 | 239.9 |
| Albany | 50.1 | 59.1 | 1.9 | 111.1 | 35.1 | 146.2 |
| Tucson | 36.8 | 65.9 | 10.6 | 113.3 | 88.0 | 201.3 |
| Shreveport (Greater) | 36.9 | 23.0 | 0.6 | 60.5 | 14.8 | 75.2 |
| Charlotte, N.C. | 62.7 | 86.8 | 4.4 | 153.9 | 11.0 | 164.9 |
| Burbank | 31.2 | 147.9 | 2.1 | 181.3 | 65.9 | 247.1 |
| Buffalo | 82.1 | 55.5 | 1.1 | 138.7 | 30.9 | 169.6 |
| NAFEC (R&D) | | | | | | |
| Raleigh/Durham | 32.1 | 71.3 | 5.9 | 109.3 | 38.2 | 1[illegible]7.5 |
| Sacramento (Metro) | 34.9 | 34.7 | 1.5 | 71.1 | 48.0 | 119.1 |
| Des Moines | 35.3 | 82.3 | 7.9 | 125.5 | 60.9 | 186.4 |
| Milwaukee (Mitchell) | 79.1 | 91.2 | 7.2 | 177.5 | 76.2 | 253.7 |

*/ Traffic activity at secondary airports is not included in this table.

SOURCE: FAA Air Traffic Activity Report, FY 1970.

it is recommended that the criteria for installing ARTS be amended to include all aircraft that use the terminal airspace. Operations at secondary airports are, therefore, included in Table 18 (p. 97). This latter table of operations was the one used in the analysis of the costs and benefits associated with the installation of ARTS III equipment at terminals with given levels of traffic activity.

## ARTS III Facility and Equipment Program Costs

Table 3 identifies the procurement and other facility and equipment costs attributable to the ARTS III program.

Table 3

ARTS III F&E PROGRAM COSTS

(In Millions of Dollars)

| | Lot 1 | Lot 2 | Lot 3 | Total |
|---|---|---|---|---|
| Number of Facilities | 12 | 23 | 29 | 64 |
| $ Contract | $11.504 | $18.178 | $22.200 (1) | $51.882 |
| $ Other (2) | 2.696 | 3.706 | 4.400 | 10.802 |
| | | 1.791 (3) | | 1.791 (3) |
| $ Total | $14.200 | $23.675 | $26.600 | $64.475 |

(1) Of the $26.311 million current contract Lot 3 ceiling, it is estimated that hardware, software and installation costing $22.200 million will be procured by the agency.

(2) Includes FAA regional engineering, site preparation, spares, factory inspection, freight, supervision of contractors, on-site activities and other "in-house" costs.

(3) Lot 3 termination cost being held by Office of Budget.

# DESCRIPTION OF THE ARTS III SIMULATION EXPERIMENT

## A. The Facility

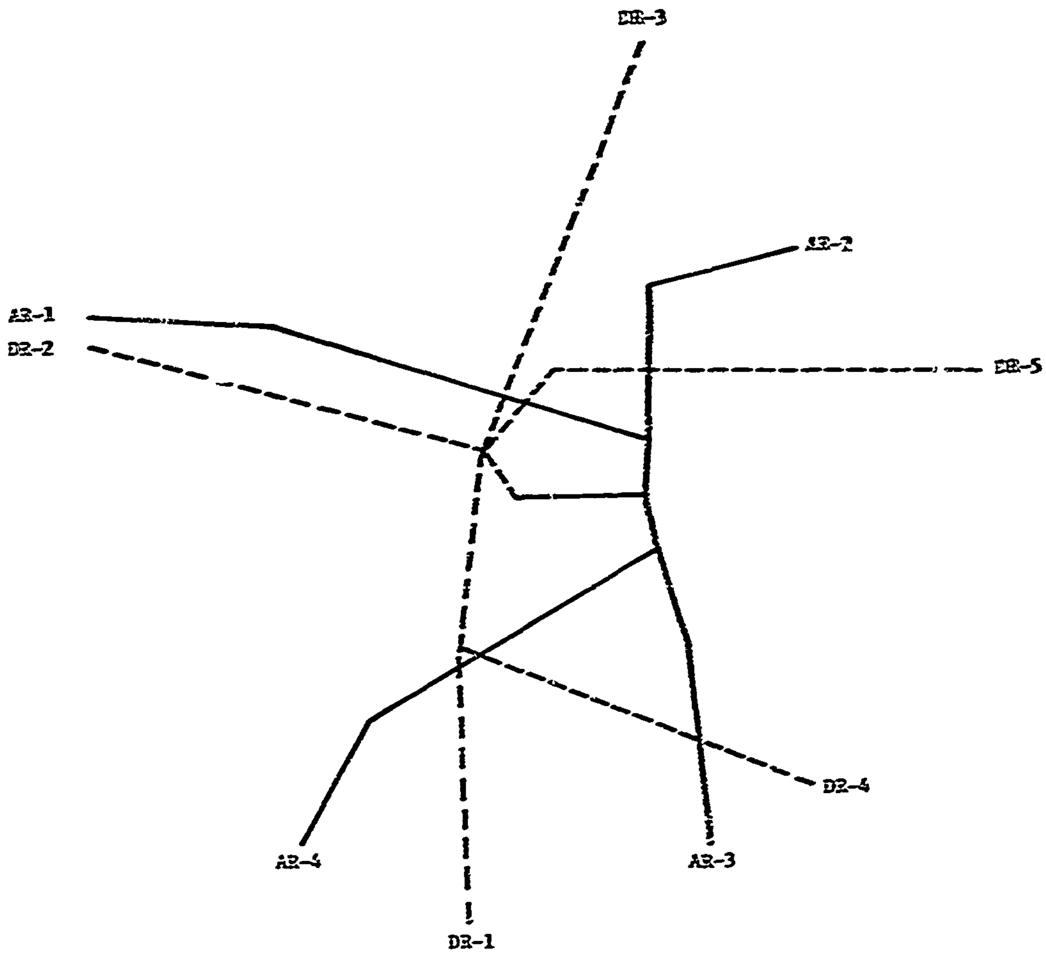
The function of the Air Traffic Control Simulation Facility is to provide, through the employment of simulation techniques, an environment in which to study, research, and investigate present and future ATC systems. These laboratories are located at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey. The recently acquired Digital Simulation Laboratory, through the use of its target generation equipment, data display equipment and data collection equipment provides a means of conducting ATC simulations under laboratory controlled conditions with unprecedented precision. Figure 2 is a photograph of the displays and equipment used in the experiment. The controller shown is a trainee from the Southern Region.

## B. The Experimental Design

An experiment which simulated the air traffic control procedures at a simple terminal configuration -- one arrival; one departure and one flight data/coordinator position, a type typical of the locations in the third lot buy -- was conducted at the NAFEC facility in March 1971. The terminal geography used in the study is shown in Figure 3.

Six teams of certificated controllers were presented with identical traffic samples using two different systems: ARTS III and manual. Each team had three members operating the positions described above. The


FEDERAL AVIATION ADMINISTRATION
Atlantic City New Jersey
71-225




ONE ARRIVAL CONTROLLER HANDLES
AR-1 63.8 NM
AR-2 40.4 NM
AR-3 37.6 NM
AR-4 52.7 NM

ONE DEPARTURE CONTROLLER HANDLES
DR-1 42.2 NM
DR-2 38.9 NM
DR-3 40.3 NM
DR-4 61.3 NM
DR-5 44.9 NM

FIGURE 3
SIMULATION GEOGRAPHY

entire experiment was repeated for a standard group of developmental (trainee) controllers. The traffic samples were replicated in three different varieties. All samples built from a low level of activity to a level estimated to be slightly higher than what the normal controller could handle. The flow of traffic could be stopped by the controller at any time, but the scheduled time of entry was recorded, and the resultant delays duly noted. The intent of the experiment was to isolate differences in the two candidate systems of control by "stressing" them under statistically controlled conditions.

The order in which the traffic samples were presented to the individual teams was statistically balanced in order to minimize any effects due to differences in the samples and to estimate any effects due to the ordering of trials. Three teams were presented with order "1" (manual trials first, followed by ARTS); three with order "2" (the order reversed) as shown in Table 4. The sequence of trials that converts the design to a schedule of four experimental runs per day is shown in Table 5. Each simulation trial run was of one hour's duration. Four runs per day represented the maximum schedule consistent with the resources allotted for the study. The experiment lasted one month and consisted of 72 trials: 36 with certificated controllers, 36 with developmental controllers. 1/

The proportion of air carrier, military and general aviation aircraft included in each of the three sample varieties -- A, B, C -- was based

1/ For a detailed description of the NAFEC test plan see Ref. 1.

Table 4

DESIGN SCHEMATIC

The traffic samples will be presented in a Latin-Square counter-balanced order (see design schematic) to control for any nonequivalence of samples themselves, yet permit systematic "partialing out" of the effects of order — e.g., first trial, second trial, third trial. A fourth sample, not used in the experiment, will be employed for shakedown, familiarization, etc., trials.

Certificated Controllers

| | | Manual | | | ARTS | | |
|---|---|---|---|---|---|---|---|
| | Trial | 1 | 2 | 3 | 1 | 2 | 3 |
| | Team | | | | | | |
| Order 1*** | I | a* | b | c | $a_1$** | $b_1$ | $c_1$ |
| | II | c | a | b | $c_1$ | $a_1$ | $b_1$ |
| | III | b | c | a | $b_1$ | $c_1$ | $a_1$ |
| Order 2 | IV | $a_1$ | $b_1$ | $c_1$ | a | b | c |
| | V | $c_1$ | $a_1$ | $b_1$ | c | a | b |
| | VI | $b_1$ | $c_1$ | $a_1$ | b | c | a |

* Traffic sample "a," a unique sequence, traffic "mix" and identities.

** Same as sample "a" exactly except for target identities.

*** Order 1 is Manual trials first, followed by ARTS system trials. Order 2 is the reverse.

An identical set of 36 runs is scheduled for the noncertificated controller teams, thus a total of 72 experimental trials.

Table 5

RUN SCHEDULE

The following matrix puts the design into a four run per day schedule:

| <u>Day</u> | | | | |
|---|---|---|---|---|
| 1. | $I_a^M$ | $IV_a^A$ | $I_b^M$ | $IV_b^A$ |
| 2. | $IV_c^A$ | $I_c^M$ | $IV_{a_1}^M$ | $I_{a_1}^A$ |
| 3. | $I_{b_1}^A$ | $IV_b^{M_1}$ | $I_{c_1}^A$ | $IV_c^{M_1}$ |
| 4. | $V_c^A$ | $II_c^M$ | $V_a^A$ | $II_a^M$ |
| 5. | $II_b^M$ | $V_b^A$ | $II_{c_1}^A$ | $V_{c_1}^M$ |
| 6. | $V_{a_1}^M$ | $II_{a_1}^A$ | $V_{b_1}^M$ | $II_{b_1}^A$ |
| 7. | $III_b^M$ | $VI_b^A$ | $III_c^M$ | $VI_c^A$ |
| 8. | $VI_a^A$ | $III_a^M$ | $VI_b^{M_1}$ | $III_{b_1}^A$ |
| 9. | $III_{c_1}^A$ | $VI_{c_1}^M$ | $III_{a_1}^A$ | $VI_{a_1}^M$ |

Teams I - VI

M = Manual System

A = Automated

upon a forecast of the numbers of these aircraft that would be airborne at a representative lower density terminal typical of the third lot procurement. The beacon transponder equipment on board each category of aircraft was programmed to be:

| | | |
|---|---|---|
| 1. Air Carrier | 95% | 4096 with Mode C |
| | 5% | 64 codes |
| 2. Military | 80% | 4096 with Mode C |
| | 10% | 64 codes |
| | 10% | without Beacon |
| 3. General Aviation | 60% | 4096 with Mode C |
| | 10% | 64 codes |
| | 30% | without Beacon |

A random sample was drawn from a universe of aircraft having the above characteristics. The specific characteristics of the sample actually employed in the simulation — repeated three times — are shown in Table 6.

Samples A, A¹ (B, B¹; C, C¹) were identical except for changes in flight identity numbers (e.g., EA 243 was changed to EA 324) in a, perhaps, overly cautious attempt to thwart "learning" or memorizing of the traffic samples. It is doubtful that such memorization could take place, and a subsequent statistical examination of the test results indicates that in all probability no learning did take place.

Samples A, B, C were random selections drawn from a population of aircraft types shown in Table 6, but all had the same general traffic characteristics shown in Table 7. After a warm-up period of 15 minutes, this table indicates that the rate of traffic activity for each sample built to a total of 36 IFR aircraft and 21 VFR aircraft during the hour.

General Characteristics of Traffic Samples A, B, C

Table 6

BY CATEGORY AND TYPE TRANSPONDER

IFR Aircraft

| | Air Carrier | | | Military | | | General Aviation | | | Totals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type Transponder: | 4096 | 64 | None | 4096 | 64 | None | 4096 | 64 | None | 4096 | 64 | None | Total |
| Arrivals | 23 | 2 | 0 | 4 | 0 | 0 | 7 | 2 | 5 | 34 | 4 | 5 | 43 |
| Departures | 25 | 1 | 0 | 4 | 1 | 0 | 6 | 2 | 4 | 35 | 4 | 4 | 43 |
| | % 94 | 6 | 0 | % 89 | 11 | 0 | % 50 | 15 | 35 | % 80 | 9 | 11 | 86 |

VFR Aircraft (10 within terminal zone; 11 at high altitude)

| Type Transponder: | 4096 | 64 | None | 4096 | 64 | None | 4096 | 64 | None | 4096 | 64 | None | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Overflights | 10 | 3 | 0 | 2 | 0 | 0 | 5 | 1 | 0 | 17 | 4 | 0 | 21 |

The rate of build-up was designed to be light during the first half-hour of each run, and heavy during the last half-hour.

Table 7

RATE OF TRAFFIC GENERATION

| Time: | 8:45 AM (build-up) | 9:00 | 9:15 | 9:30 | 9:45 | 10:00 | Total for Hour |
|---|---|---|---|---|---|---|---|
| IFR | | | | | | | |
| Arrivals | 5 | 6 | 9 | 13 | 10 | | 43 |
| Departures | -- | 8 | 10 | 13 | 12 | | 43 |
| VFR | (Constant rate of 21 per hour) | | | | | | |

## STUDY OUTPUTS

### A. Performance Measures

A large number of measures were determined prior to the conduct of the experiment to be significant 2/ indicators of the complex job of controlling air traffic in the terminal airspace. These are identified in Table 8, and are summarized below by category: the actual record of experimental results, which are keyed to Table 8, is shown in Table 8A.

| Index No. | Description Category |
|---|---|
| 1-3 | Aircraft Handled |
| 4-11 | Time in System |
| 12-41 | Communications |
| 45-48 | Advisories (observed by referee) |
| 51-56 | Conflicts |

The above categories of performance were monitored by computer and recorded automatically with the exception of category 45-48, Advisories "observed by referee." It was felt, prior to the conduct of the experiment that certain critical facets of safety in performance could not be monitored automatically. For example, a controller using ARTS might have the additional and highly relevant information that a VFR aircraft with a Mode C transponder was at a conflict altitude with an IFR

2/ For a detailed description and rationale for recording these measures, see Ref. 2. It is important to note that the specification of these performance indices was made three months prior to the conduct of the experiment.

Table 8

| Index No. | Description of Indices of Performance |
|---|---|
| 1 | Number arrivals |
| 2 | Number departures |
| 3 | Total arrivals and departures |
| 4 | Completed system time, average for arrivals |
| 5 | Completed system time, average for departures |
| 6 | Actual flight time, start to runway, average for arrivals |
| 6-8 | Index 6 less index 8 = Actual flight time |
| 7 | Actual flight time, runway to termination, average for departures |
| 8 | Actual flight time, handoff to runway, average for arrival |
| 9 | Actual flight time, runway to handoff, average for departures |
| 10 | Total delay time, average for arrivals |
| 11 | Total delay time, average for departures |
| | Time in communications: |
| 12 | Arrival controller - radio |
| 13 | Arrival controller - phone |
| 14 | Departure controller - radio |
| 15 | Departure controller - phone |
| 16 | Controller team - radio |
| 17 | Controller team - phone |
| | Requests for reidentification: |
| 18 | Arrival controller |
| 19 | Departure controller |
| 20 | Controller team |
| | Requests for altitude verification: |
| 21 | Arrival controller |
| 22 | Departure controller |
| 23 | Controller team |
| | Directives for steering vectors: |
| 24 | Arrival controller |
| 25 | Departure controller |
| 26 | Controller team |

(Cont'd)

Table 8 (Cont'd)

| Index No. | Description of Indices of Performance |
|---|---|
| | Average communications time per aircraft: |
| 27 | Arrival controller - radio |
| 28 | Arrival controller - phone |
| 29 | Departure controller - radio |
| 30 | Departure controller - phone |
| 31 | Controller team - radio |
| 32 | Controller team - phone |
| | Average requests for reidentification per aircraft: |
| 33 | Arrival controller |
| 34 | Departure controller |
| 35 | Controller team |
| | Average requests for altitude verification per aircraft: |
| 36 | Arrival controller |
| 37 | Departure controller |
| 38 | Controller team |
| | Average directives for steering vectors per aircraft: |
| 39 | Arrival controller |
| 40 | Departure controller |
| 41 | Controller team |
| 45 | Number of traffic advisories without altitude information |
| 46 | Number of traffic advisories with altitude information |
| 47 | Number of traffic avoiding actions without altitude information |
| 48 | Number of traffic avoiding actions with altitude information |
| | Number of separation standards violations: |
| 51 | VFR/IFR |
| 52 | IFR/IFR |
| 53 | Gross |

(Cont'd)

Table 8 (Cont'd)

| Index No. | Description of Indices of Performance |
|---|---|
| | Total time in violation: |
| 54 | VFR/IFR |
| 55 | IFR/IFR |
| 56 | Gross |
| | Probability a communication channel is busy |
| 61 | Radio - Arrival Controller |
| 62 | Radio - Departure Controller |
| 63 | Phone - Arrival Controller |
| 64 | Phone - Departure Controller |
| 65 | Phone - Coordinator Controller |
| | Expected duration of call, given communication channel is busy (expected wait time for clear transmission): |
| 71 | Radio - Arrival Controller |
| 72 | Radio - Departure Controller |
| 73 | Phone - Arrival Controller |
| 74 | Phone - Departure Controller |
| 75 | Phone - Coordinator Controller |
| 81-89 | Indices of "orderliness"; alternative weighting schemes |

aircraft that he was working. A traffic advisory or a directional vector would, therefore, be given to this IFR aircraft -- on a time available basis -- in accordance with the present legally prescribed procedures for controllers. On the other hand, the controller using the manual system would be ignorant of the altitude of the VFR aircraft. No advisory or change in directional vector could be given on the basis of unknown information. A distortion in test results would occur. The critical avoidance of an unsafe situation would be recorded, automatically, only as an increase in the time in terminal for an IFR aircraft. In addition, it would clearly not be valid to test for statistically significant differences between the ARTS and manual systems of control since these indices (46 and 48) are logically fixed at zero for the manual system. In the same way, no statistical interpretation is possible for indices (45 and 47) which measure the number of times advisories were given unnecessarily by a manual controller who did not have relevant altitude information concerning VFR aircraft in the vicinity. For this reason, it was decided to record category 45-48, derived by observation, in a separate effort and to subject the data to independent evaluation. This effort proved unproductive. No useful information was obtained because, apparently, controllers think quite far ahead in maintaining aircraft separation. It was, therefore, not possible, without reconstructing the total thought processes of the controller, to determine whether some specific evasive action was prompted by the display of altitude information for a given aircraft. But, despite the fact that category 45-48 provided no additional data, the situations described

above were evidently captured sufficiently by the computer monitoring of the other categories of performances: 1) the evasive actions taken by the ARTS controllers were, obviously, contributing factors to the observed reduction in conflicts, category 50; 2) the fewer unnecessary advisories given by ARTS contributed to the reduced numbers of radio communications observed for this system, category 12.

The following indices were derived analytically from the above, observed, measures:

| Index No. | Description Category |
|---|---|
| 60-75 | Communication Channel Congestion |
| 80-90 | Indices of "orderliness" |

The indices of channel congestion (60-75) are merely translations of data previously obtained in category 12-41 into probability estimates that some channel of communication will be busy, and into an estimate of the expected time it would take for the channel to clear. This is a convenient method that provides the analytical platform to allow for the exchange of significant reductions in Communications Workload into the more critical currency, Safety. Since it has been argued previously that such a translation involves a double counting of benefits, no such translation of the increased probabilities of receiving a busy signal into an increasing probability of a conflict was attempted. And, no additional importance was attributed to the fact that the experiment demonstrated a significant reduction, at a high degree of statistical confidence, in the probability that a channel would be busy or to the fact that there was a significant

reduction in the expected waiting time for clearance. These facts were considered to be mere reflections of significant reductions in Communications Workload which have already been observed in category 12-41.

A separate and detailed analysis of category 50, Conflicts, was undertaken with the help of a newly devised measure, an index of "orderliness." 3/ This measure was determined from a set of mathematical equations that attempted to represent an aircraft's flight path. By extending the mathematical vector of an aircraft's heading and speed it is possible to predict the minimum separation distance between targets for any given interval of time. The index then counts all instances in which this distance plus vertical separation are below established legal standards. A violation of airspace separation standards is predicted to occur unless the aircraft changes its heading, speed, or altitude. Different indices were defined by using various weighting schemes in an attempt to adequately describe the severity of the conflict. Are conflicts which are one mile apart twice as severe as those which are two miles apart (an inversely proportional weighting scheme); are they four times as severe (inversely proportional to the square of the distance)? Several alternative weighting schemes were investigated. The most recent of these versions -- index 89 -- is reported in Table 8. However, the conclusions were found to be not severely affected by the particular weighting scheme selected. As anticipated, the index of

3/ A measure defined by A. G. Halverson of NAFEC. For a detailed description of this measure, see Ref. 3.

"orderliness" not only proved to be a good proxy for the number of conflicts, but to have certain advantages over a direct measure of these conflicts. For one thing, the analytically derived index of "orderliness" reflects th. severity of the violation, the direct count of the number of conflicts does not. Indices 54-56, Time in Conflict, reflect severity to a limited degree -- i.e., it is worse to be in conflict for 50 seconds rather than 40 -- but indices 80-90 impart both a dimension of time and distance to the conflict. Further, it was assumed that the record of conflicts would provide a paucity of information suited to further analysis. Conflicts are unusual events and it is difficult to look for patterns and attribute them to causes when the data are not sufficient for this purpose. However, the index of "orderliness" is a highly visible number that can be derived analytically at any instant in time. Moreover, as an index capable of continuous measurement it is amenable to mathematical treatment by unsophisticated methods. Conflicts, on the other hand, are a discrete variable. At any instant in time, either there are conflicts or there are none. Dependent variables of zero magnitude require special analytical treatment. In summary, indices 80-90 are continuous measures of large dimension especially suited for the purpose of evaluating patterns of conflict, but only if it can be established that they are an appropriate surrogate for the actual record of conflicts.

The Transportation Systems Center of the Department of Transportation was charged with the responsibility of determining whether any of the

alternative schemes for estimating the index of orderliness could be considered as an appropriate proxy for conflicts. 4/ As a result of this work it was determined that any and all of the alternative schemes for calculating the index of "orderliness" could be used as a continuous measure of conflicts. The two measures, conflicts and the index of orderliness, were correlated to a very high order of statistical identity.

Index 89, the example "orderliness" measure included in this report, is shown in Table 8A as the average value for one hour of simulated operations. Since a detailed examination of the record of conflicts was envisioned as an essential element of this study, a major output category, based on the index of "orderliness," was added to the list of indices shown in Table 8. An instantaneous count of the kinds of targets -- their number, the method of control (IFR or VFR), the type of transponder -- was recorded at one minute intervals. These data together with the determination of the number of conflicts and a derived estimate of the index of orderliness were recorded for each controller position. The conclusions drawn from an analysis of this record will be reported separately in Appendix A.

B. Reporting Format

A total of 36 observations for each of the two controller groups were made for the indices listed in Table 8. An example of the reporting

4/ For a detailed description of this work, see Ref. 4.

format is shown for Index 13 in Table 9. Three data entries were made for each team, sample and control system: a) first half-hour; b) second half-hour; and c) total for the hour. Table 9 is a record for the field (trainee) group of controllers, a group that was used in the latter half of the experiment. The numbers in the upper left hand corner of the entry represent the number of the trial hour being reported: hours 37 to 72.

Table 9

FIELD CONTROLLERS

INDEX 13

Arrival

Total Time - Phone, in secs.

| TEAMS | | MANUAL SYSTEM A | MANUAL SYSTEM B | MANUAL SYSTEM C | | ARTS A | ARTS B | ARTS C |
|---|---|---|---|---|---|---|---|---|
| | | 37 | 39 | 42 | | 44 | 45 | 47 |
| | 1st | 102 | 109 | 93 | | 71 | 17 | 39 |
| 1 | 2nd | 94 | 92 | 110 | | 59 | 99 | 34 |
| | Tot | 196 | 201 | 203 | | 130 | 116 | 73 |
| | | 52 | 53 | 50 | | 58 | 60 | 55 |
| | 1st | 134 | 113 | 141 | | 31 | 39 | 60 |
| 2 | 2nd | 111 | 124 | 123 | | 8 | 41 | 36 |
| | Tot | 245 | 237 | 264 | | 39 | 80 | 96 |
| | | 66 | 61 | 63 | | 71 | 68 | 69 |
| | 1st | 134 | 146 | 127 | | 55 | 36 | 42 |
| 3 | 2nd | 148 | 137 | 159 | | 40 | 75 | 55 |
| | Tot | 282 | 283 | 286 | | 95 | 111 | 97 |
| | | 43 | 46 | 48 | | 38 | 40 | 41 |
| | 1st | 91 | 111 | 105 | | 39 | 15 | 48 |
| 4 | 2nd | 67 | 69 | 138 | | 7 | 33 | 23 |
| | Tot | 158 | 180 | 243 | | 46 | 48 | 71 |
| | | 57 | 59 | 56 | | 51 | 54 | 49 |
| | 1st | 134 | 118 | 120 | | 47 | 23 | 60 |
| 5 | 2nd | 170 | 143 | 138 | | 44 | 57 | 22 |
| | Tot | 304 | 261 | 258 | | 91 | 80 | 82 |
| | | 72 | 67 | 70 | | 65 | 62 | 64 |
| | 1st | 114 | 137 | 100 | | 33 | 29 | 32 |
| 6 | 2nd | 99 | 126 | 107 | | 18 | 60 | 20 |
| | Tot | 213 | 263 | 207 | | 51 | 89 | 52 |

1st - 1-30 Min.
2nd - 30-60 Min.
Tot. - 1-60 Min.

## TEST RESULTS AND THEIR ANALYSIS

### A. Results

A detailed summary of the experimental results for all indices described in Table 8 is shown below as Table 8A; index number designations are keyed to Table 8. Each entry is the arithmetic mean of 18 observations (6 teams, 3 samples) for each of the two systems of control, manual and ARTS, summarized by half hour and hourly totals.

### B. Analysis

A statistical analysis designed to test for significant differences in the mean values obtained for the two systems of control was performed. The level of statistical significance that can be attributed to any observed differences in test results is indicated in Table 8A, under "significance." The numbers shown -- .01, .05, etc. -- are called alpha ($\alpha$) values and are to be interpreted as meaning that the observed differences in mean values as large as those shown in Table 8A could be expected to be due to chance only $\alpha$ percent (i.e., 1 percent, 5 percent, etc.) of the time. The standard "t" test for determining significant differences in means was employed. An analysis of variance was performed in order to eliminate those sources of error which could be accounted for statistically. The residual, experimental error, was used as the denominator for the "t" test. Those differences which resulted in $\alpha$ values of 0.25 or less are shown in Table 8A. This means that there

Table 8A

SUMMARY DESCRIPTION OF

INDICES OF PERFORMANCE

AND DATA RESULTS FOR

ARTS III VS. MANUAL

SIMULATION CERTIFICATED

AND TRAINEE CONTROLLERS

Three row entrees appear for each index to indicate:

1. 1st half hour (low traffic activity)

2. 2nd half hour (high traffic activity)

3. Full hour (combined traffic activity)

Table 8A (Cont'd)

DATA RESULTS SUMMARY

| | CERTIFICATED CONTROLLERS | | | NON-CERTIFICATED CONTROLLERS | | |
|---|---|---|---|---|---|---|
| INDEX | MANUAL | ARTS III | SIGNIFICANCE | MANUAL | ARTS III | SIGNIFICANCE |
| | number of aircraft | | | | | |
| 1 | 10.61 | 10.28 | .25 | 10.61 | 10.56 | |
| | 14.50 | 14.06 | | 13.61 | 13.50 | |
| | 25.11 | 24.33 | | 24.22 | 24.06 | |
| 2 | 17.44 | 17.61 | | 17.94 | 17.83 | |
| | 19.83 | 20.33 | | 22.50 | 22.83 | |
| | 37.28 | 37.94 | | 40.44 | 40.67 | |
| 3 | 28.06 | 27.39 | | 28.56 | 28.39 | |
| | 34.33 | 34.39 | | 36.11 | 36.33 | |
| | 62.39 | 62.28 | | 64.67 | 64.72 | |
| | time in seconds | | | | | |
| 4 | 840 | 857 | .25 | 812 | 825 | |
| | 1117 | 1189 | .25 | 1130 | 1153 | |
| | 998 | 1044 | .25 | 990 | 1008 | |
| 5 | 721 | 722 | | 702 | 705 | |
| | 907 | 896 | | 827 | 831 | |
| | 819 | 814 | | 771 | 775 | |
| 6 | 834 | 852 | .25 | 806 | 818 | |
| | 1083 | 1172 | .25 | 1095 | 1127 | |
| | 976 | 1033 | .25 | 967 | 991 | |
| 6-8 | 216 | 205 | .25 | 200 | 186 | .25 |
| | 317 | 310 | | 297 | 250 | .10 |
| | 274 | 264 | | 255 | 221 | .05 |
| 7 | 628 | 636 | .05 | 627 | 627 | |
| | 650 | 651 | | 667 | 665 | |
| | 639 | 644 | | 649 | 649 | |
| 8 | 619 | 647 | .25 | 606 | 632 | .05 |
| | 766 | 862 | .10 | 798 | 877 | .10 |
| | 703 | 769 | .10 | 712 | 770 | .05 |
| 9 | 187 | 197 | .25 | 176 | 166 | .25 |
| | 193 | 196 | | 475 | 494 | |
| | 190 | 196 | | 184 | 171 | .25 |

(Cont'd)

Table 8A (Cont'd)

| | CERTIFICATED CONTROLLERS | | | NON-CERTIFICATED CONTROLLERS | | |
|---|---|---|---|---|---|---|
| INDEX | MANUAL | ARTS III | SIGNIFICANCE | MANUAL | ARTS III | SIGNIFICANCE |
| 10 | 124 | 148 | .25 | 99 | 104 | |
| | 352 | 423 | .25 | 348 | 410 | .25 |
| | 255 | 304 | .25 | 238 | 276 | .25 |
| 11 | 19 | 20 | | 4 | 6 | |
| | 183 | 173 | | 83 | 90 | |
| | 100 | 96 | | 40 | 46 | |
| 12 | 316 | 280 | .01 | 349 | 330 | .10 |
| | 457 | 416 | .25 | 472 | 481 | |
| | 773 | 695 | .05 | 821 | 811 | |
| 13 | 123 | 35 | .01 | 118 | 40 | .01 |
| | 143 | 44 | .01 | 120 | 41 | .01 |
| | 266 | 78 | .01 | 238 | 80 | .01 |
| 14 | 251 | 215 | .10 | 247 | 224 | .25 |
| | 300 | 260 | .25 | 329 | 310 | .25 |
| | 550 | 475 | .10 | 576 | 535 | .25 |
| 15 | 165 | 36 | .01 | 193 | 27 | .01 |
| | 227 | 73 | .01 | 264 | 35 | .01 |
| | 392 | 110 | .01 | 457 | 62 | .01 |
| 16 | 566 | 494 | .05 | 596 | 555 | .10 |
| | 756 | 676 | .10 | 801 | 791 | |
| | 1323 | 1170 | .05 | 1396 | 1346 | .25 |
| 17 | 292 | 79 | .01 | 321 | 73 | .01 |
| | 438 | 195 | .01 | 464 | 133 | .01 |
| | 731 | 274 | .01 | 786 | 206 | .01 |
| | number of actions | | | | | |
| 18 | .56 | .00 | .01 | 1.17 | .00 | .01 |
| | 2.00 | .11 | .05 | 4.11 | .06 | .10 |
| | 2.56 | .11 | .01 | 5.28 | .06 | .05 |
| 19 | .06 | .28 | .25 | .11 | .00 | .25 |
| | .56 | .22 | .05 | .33 | .11 | |
| | .61 | .50 | | .44 | .11 | .25 |
| 20 | .61 | .28 | .25 | 1.28 | .00 | .01 |
| | 2.56 | .33 | .05 | 4.44 | .17 | .10 |
| | 3.17 | .61 | .01 | 5.72 | .17 | .05 |
| 21 | 7.11 | 2.61 | .25 | 2.44 | .83 | .05 |
| | 6.06 | 2.78 | | 2.83 | 2.11 | |
| | 13.17 | 5.39 | .25 | 5.28 | 2.94 | .05 |

(Cont'd)

Table 8A (Cont'd)

| | CERTIFICATED CONTROLLERS | | | NON-CERTIFICATED CONTROLLERS | | |
|---|---|---|---|---|---|---|
| INDEX | MANUAL | ARTS III | SIGNIFICANCE | MANUAL | ARTS III | SIGNIFICANCE |
| 22 | 16.11 | 3.61 | .05 | 10.61 | 2.56 | .05 |
| | 18.56 | 5.06 | .01 | 13.89 | 4.44 | .05 |
| | 34.67 | 8.67 | .05 | 24.50 | 7.00 | .01 |
| 23 | 23.22 | 6.22 | .05 | 13.06 | 3.39 | .05 |
| | 24.61 | 7.83 | .05 | 16.72 | 6.56 | .01 |
| | 47.83 | 14.06 | .05 | 29.78 | 9.94 | .01 |
| 24 | 36.28 | 36.39 | | 48.06 | 46.06 | .10 |
| | 55.44 | 61.06 | .25 | 64.89 | 71.11 | .25 |
| | 91.72 | 97.44 | .25 | 112.94 | 117.17 | |
| 25 | 10.72 | 8.89 | | 9.83 | 10.00 | |
| | 11.89 | 12.39 | | 12.83 | 13.50 | |
| | 22.61 | 21.28 | | 22.67 | 23.50 | |
| 26 | 47.00 | 45.28 | | 57.89 | 56.06 | |
| | 67.33 | 73.44 | .25 | 77.72 | 84.61 | .10 |
| | 114.33 | 118.72 | | 135.61 | 140.67 | .25 |
| | seconds per aircraft | | | | | |
| 27 | 29.67 | 27.28 | .10 | 33.22 | 31.39 | .25 |
| | 31.72 | 29.78 | .25 | 35.22 | 35.67 | |
| | 30.83 | 28.61 | .10 | 34.17 | 33.72 | |
| 28 | 11.78 | 3.56 | .01 | 11.11 | 3.78 | .01 |
| | 10.00 | 3.22 | .01 | 9.00 | 3.00 | .01 |
| | 10.67 | 3.28 | .01 | 9.89 | 3.39 | .01 |
| 29 | 14.33 | 12.11 | .05 | 13.78 | 12.56 | .25 |
| | 15.06 | 12.83 | .10 | 14.67 | 13.56 | .05 |
| | 14.72 | 12.50 | .05 | 14.50 | 13.28 | .05 |
| 30 | 9.44 | 2.11 | .01 | 10.89 | 1.50 | .01 |
| | 11.72 | 3.67 | .01 | 11.67 | 1.67 | .01 |
| | 10.56 | 2.94 | .01 | 11.44 | 1.44 | .01 |
| 31 | 20.17 | 17.67 | .01 | 21.00 | 19.50 | .25 |
| | 22.33 | 19.61 | .10 | 22.28 | 21.78 | |
| | 21.28 | 18.72 | .05 | 21.61 | 20.67 | .25 |
| 32 | 10.39 | 2.83 | .01 | 11.17 | 2.67 | .01 |
| | 12.94 | 5.56 | .01 | 12.94 | 3.67 | .01 |
| | 11.72 | 4.39 | .01 | 12.17 | 3.28 | .01 |

(Cont'd)

Table 8A (Cont'd)

| | CERTIFICATED CONTROLLERS | | | NON-CERTIFICATED CONTROLLERS | | |
|---|---|---|---|---|---|---|
| INDEX | MANUAL | ARTS III | SIGNIFICANCE | MANUAL | ARTS III | SIGNIFICANCE |
| | actions per aircraft | | | | | |
| 33 | .05 | .00 | .01 | .11 | .00 | .01 |
| | .14 | .01 | .05 | .32 | .00 | .10 |
| | .10 | .00 | .01 | .21 | .00 | .10 |
| 34 | .00 | .02 | .25 | .01 | .00 | .25 |
| | .03 | .01 | .05 | .01 | .00 | |
| | .02 | .01 | | .01 | .00 | .25 |
| 35 | .02 | .01 | .10 | .04 | .00 | .01 |
| | .08 | .01 | .05 | .12 | .00 | .10 |
| | .05 | .01 | .01 | .09 | .00 | .05 |
| 36 | .68 | .25 | .25 | .23 | .08 | .05 |
| | .42 | .20 | | .21 | .15 | |
| | .52 | .22 | .25 | .22 | .12 | .05 |
| 37 | .92 | .21 | .05 | .59 | .14 | .05 |
| | .93 | .24 | .01 | .62 | .20 | .01 |
| | .92 | .22 | .01 | .61 | .17 | .01 |
| 38 | .82 | .22 | .05 | .46 | .12 | .01 |
| | .71 | .22 | .01 | .46 | .18 | .05 |
| | .76 | .22 | .05 | .45 | .15 | .01 |
| 39 | 3.43 | 3.58 | | 4.57 | 4.40 | |
| | 3.83 | 4.34 | .05 | 4.82 | 5.28 | .10 |
| | 3.65 | 4.00 | .05 | 4.70 | 4.89 | .05 |
| 40 | .62 | .50 | .25 | .54 | .56 | |
| | .60 | .62 | | .57 | .59 | |
| | .60 | .56 | | .56 | .58 | |
| 41 | 1.68 | 1.63 | | 2.03 | 1.98 | |
| | 1.96 | 2.13 | .25 | 2.16 | 2.34 | .25 |
| | 1.83 | 1.90 | | 2.10 | 2.18 | .10 |
| | number of actions | | | | | |
| 45 | 5.67 | .67 | .01 | 5.83 | 3.72 | .10 |
| 46 | .00 | .22 | .25 | .00 | .89 | .25 |
| 47 | .39 | .00 | | .00 | .00 | |
| 48 | .00 | .00 | | .00 | .11 | |
| 51 | .50 | .44 | | .06 | .06 | |
| | 1.50 | 1.11 | .25 | 1.28 | 1.78 | .25 |
| | 2.00 | 1.56 | .25 | 1.33 | 1.83 | .25 |

(Cont'd)

Table 8A (Cont'd)

| | CERTIFICATED CONTROLLERS | | | NON-CERTIFICATED CONTROLLERS | | |
|---|---|---|---|---|---|---|
| INDEX | MANUAL | ARTS III | SIGNIFICANCE | MANUAL | ARTS III | SIGNIFICANCE |
| 52 | .94 | .78 | | 1.28 | .78 | .10 |
| | 4.06 | 3.56 | | 4.06 | 1.89 | .10 |
| | 5.00 | 4.33 | | 5.33 | 2.67 | .05 |
| 53 | 4.44 | 4.28 | | 5.78 | 5.94 | |
| | 15.89 | 16.00 | | 18.94 | 18.67 | |
| | 20.33 | 20.28 | | 24.72 | 24.61 | |
| | time in seconds | | | | | |
| 54 | 64 | 32 | .25 | 10 | 14 | |
| | 85 | 58 | .05 | 65 | 87 | |
| | 149 | 90 | .05 | 75 | 101 | .25 |
| 55 | 37 | 19 | .25 | 65 | 40 | .25 |
| | 178 | 182 | | 354 | 142 | .10 |
| | 214 | 201 | | 419 | 182 | .10 |
| 56 | 238 | 171 | .05 | 262 | 220 | .10 |
| | 767 | 736 | | 947 | 781 | |
| | 1005 | 907 | | 1209 | 1001 | |
| | probability | | | | | |
| 61 | .176 | .157 | .01 | .193 | .184 | .25 |
| | .253 | .231 | .25 | .262 | .267 | |
| | .215 | .193 | .05 | .227 | .225 | |
| 62 | .141 | .118 | .05 | .137 | .124 | .25 |
| | .168 | .146 | .25 | .183 | .172 | .10 |
| | .152 | .132 | .10 | .159 | .149 | .25 |
| 63 | .068 | .020 | .01 | .066 | .022 | .01 |
| | .078 | .022 | .01 | .067 | .021 | .01 |
| | .074 | .022 | .01 | .066 | .022 | .01 |
| 64 | .091 | .021 | .01 | .108 | .015 | .01 |
| | .126 | .042 | .01 | .147 | .019 | .01 |
| | .108 | .031 | .01 | .127 | .018 | .01 |
| 65 | .002 | .003 | | .006 | .004 | |
| | .037 | .043 | | .046 | .031 | .10 |
| | .021 | .023 | | .025 | .018 | .25 |

(Cont'd)

Table 8A (Cont'd)

| | CERTIFICATED CONTROLLERS | | | NON-CERTIFICATED CONTROLLERS | | |
|---|---|---|---|---|---|---|
| INDEX | MANUAL | ARTS III | SIGNIFICANCE | MANUAL | ARTS III | SIGNIFICANCE |
| | time in seconds | | | | | |
| 71 | 2.14 | 2.04 | .25 | 2.40 | 2.42 | |
| | 2.19 | 2.01 | .10 | 2.33 | 2.42 | .25 |
| | 2.18 | 2.03 | .10 | 2.36 | 2.42 | |
| 72 | 2.47 | 2.37 | | 2.69 | 2.70 | |
| | 2.21 | 2.20 | | 2.50 | 2.59 | |
| | 2.33 | 2.28 | | 2.58 | 2.64 | |
| 73 | 7.63 | 5.65 | .01 | 7.25 | 6.33 | .05 |
| | 9.71 | 6.59 | .01 | 8.24 | 6.32 | .01 |
| | 8.81 | 6.25 | .01 | 7.80 | 6.52 | .01 |
| 74 | 10.14 | 7.15 | | 7.91 | 7.25 | |
| | 8.66 | 8.38 | | 9.47 | 7.80 | .10 |
| | 9.69 | 8.31 | | 8.82 | 8.67 | |
| 75 | 1.60 | 3.00 | | 3.69 | 1.96 | .25 |
| | 11.66 | 10.91 | | 7.76 | 5.32 | .10 |
| | 11.72 | 10.88 | | 7.76 | 5.37 | .10 |
| | index of orderliness | | | | | |
| 89 | 277 | 159 | .25 | 425 | 172 | |

is a statistical likelihood of three out of four that the observed differences were due to some functional cause; not chance.

> A short note is, perhaps, in order to remind the reader that the $\alpha$ level at which an observed difference is considered to be significant is not a matter to be settled by the statistician. A rational decision requires that the practical, not statistical, significance of a difference be considered. Only the manager responsible for choosing between alternative systems of equipment can assign the appropriate practical value to be placed on differences between candidate systems. To repeat, the statistician can make quantitative estimates of the differences in means and he can indicate the likelihood that these differences are attributable to real or functional causes, if certain assumptions about the frequency distribution of events are made. But, the relevant determinant of differences between systems must always depend upon the costs involved in making either of the two possible types of statistical error: rejecting a hypothesis that the systems are not different when, in fact, they are different, b) accepting a hypothesis that the systems are different when, in fact, they are not. The costs of making a mistake in either of the above two ways determine the practical significance of the experimental results. The statistician's tools can tell us nothing about this.

The costs involved in accepting the hypothesis that ARTS equipment results in fewer conflicts than the use of the present equipment when, in fact, it does not, are the costs associated with buying more expensive equipment, needlessly. However, if we reject the hypothesis that ARTS is safer when, indeed, it is, then we are making a mistake of greater dimension. In order to guard against this very costly error -- the precise degree of cost depends, remember, on the subjective judgment of the person charged with making the decision -- we should be willing to accept the premise that ARTS is better than manual at a practical

level of significance that is in considerable excess of statistical significance. [5]

On the other hand, there are cases in which the practical level of significance may be less than some conventional level of statistical significance. For example, indications of differences in communication workloads, especially those involved with telephone communications have less practical significance. Ignoring, for the moment, any ancillary considerations of safety due to the fact that lines may be busy at inopportune times, differences in the number of telephone communications can always be accommodated, cheaply, by installing more lines. (Not so, perhaps, for radio communications, especially if the limit of available frequencies has been reached. However, this limit is not likely to be reached at any time in the near future for the specific terminal locations in our study.) For this reason, we should insist on very high levels of statistical significance before we accept the premise that ARTS requires less time in phone communication than the manual system. The level of statistical significance determined by experiment did prove to be very high; $\alpha = 0.01$.

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5/ A succinct description of the point we are making can be found in the New York Daily News of May 15, 1972, (p. 20). Under the headline "Heart Drug Dropped After Death Rate Study" there appears the following quotation attributed to Dr. Jeremiah Stamler, a noted cardiologist at Northwestern University Medical School in Chicago: "The number of deaths," he declared, "was not statistically significant but one prefers not to wait for statistical significance -- you quit. In medical research, above all there is a responsibility to avoid harm. That is why we made the decision."

Most importantly, no data revealed by the experiment indicate that ARTS is less safe than the manual system. There is no evidence, however implicit, that ARTS does harm.

> To the contrary, the evidence indicates that the potential for increased safety is probably being understated in the table of results presented. If inferences are drawn from the entire second half of the experiment which used trainee controllers, the potential exists for the certificated controller to do even better in their ability to separate IFR x IFR aircraft. It can be argued that the trainee controller's improved performance with ARTS was the result of this group being less accustomed to the manual system. The opportunity to discard old habits and to utilize the automated system more fully will be realized, in time, to a greater extent by the certificated controller.

It is also essential to point out that it was never the study's intention to analyze the experimental data for isolated instances of statistical significance. Some 240 measures were recorded -- about 80 separate indices in three time periods -- and it would be a simple, as well as incorrect matter to highlight those indices which favored ARTS to a statistically significant degree, and ignore all others. We have already indicated how statistical significance can be an irrelevant criterion for decision making, but since this was the criterion established in discussions with the panel of reviewers in the Department of Transportation and the Office of Management and Budget, we had no choice other than to accept their dictate of this criterion. However, we voluntarily imposed an additional, more stringent and valid, standard of analysis based upon logical, and not merely statistical, considerations. We attempted to determine the causal or inherent differences between systems. Explanations or hypotheses to explain these anticipated

differences were proposed before the running of the experiment. Differences observed in performance measures had to be accounted for by a causal link to a real difference between the ARTS and manual systems. For example, it was anticipated that the substantive contribution made by ARTS III equipment was the continual display of information relevant to the control of aircraft: alphanumeric identity, ground speed and altitude. It was expected that a controller would react to this information by taking an increased number of actions to avoid conflicts; actions which, obviously, would not be taken in the absence of such information. Suffice it to say, we did observe that index 26 -- "directives for steering vectors" -- were higher for the ARTS system. With more steering vectors given under ARTS, consistent with hypothesis that the data block is relevant to the control of aircraft, there is then no logical explanation to account for an expectation that the time spent in terminal control -- index 8 -- would be less using ARTS. The experiment verifies that it is not.

Finally, we imposed a standard for the analysis that is similar to the standard of statistical significance in that it was dictated to us by the panel of reviewers, and is equally susceptible to spurious or irrelevant conclusions. This additional standard limited the analysis to only those differences which could be translated into dollar benefits.

> Throughout history, the essence of the contribution made by automation from the days before the invention of the plow, to the sewing machines of the 19th century, and including the wonders of today's technology has been the ability to reduce the variation in individual performance. We now live in a world where few of us ever know the pleasure of nibbling at a tub of great tasting butter, but we seldom are also disappointed in the other direction. "Homogenized" is the label that typifies today's products and services. Our

steel driving machines, most probably, are still not able to compete with the late and legendary John Henry, but they can out drive everyone else. It is the ability to produce an unvarying standard of performance from a larger number of workers that is the true miracle of automation. So, too, with ARTS III, it was expected that some individual controller using older methods could outperform other controllers using automated techniques. The more important question was whether all controllers, including the lowliest performer, could be brought to a standard that demonstrated a narrow range in performance for all users of the equipment. More efficient planning for facilities and manpower, and less selective recruiting methods from elite population groups only, would result. Therefore, provision was made to analyze the standard deviation -- a statistical measure of the variation in individual controller performance -- for every index specified in Table 8. But, despite the importance of this measure, there is no objective way to assign dollar benefits to it. For example, it is possible to report that the standard deviation for index 54 -- "time in conflicts for IFR x VFR aircraft" -- was 80 seconds for the certificated controller using ARTS and 127 seconds for the manual controller. Based upon the above discussion of what it is that automation really contributes, it would seem that this is useful and relevant information to the decision maker, but since it cannot be expressed as a dollar benefit, no listing of deviations recorded for the study's indices of performance is provided. 6/

For the same reason, there was no way to assign dollar benefits to ARTS' ability to readily identify emergency situations. Special codes assigned to a variety of flight emergencies are an invaluable aid to air traffic control. However, it was not possible to simulate emergency situations in the present study. And, even if we could simulate these situations the result would be a perverse one which found that ARTS benefits are negative. The only way that an emergency situation could be reflected in our study would be in the increased communications workload recorded by the ARTS facility working the emergency.

6/ The complete body of data for all indices is available from the FAA Office of Aviation Economics to anyone with a legitimate need to know. The calculation of the appropriate measures of standard deviations can be made from this body of data. This calculation and their interpretation are left as exercises for the interested reader.

In summary, all observed differences in experimental results which have led us to conclude that ARTS equipment should be installed at those terminal locations specified in the third lot option meet the following criteria: 1) they are statistically significant, 2) they are logically tenable and causally linked to differences in equipment technology, and 3) they are based on quantifiable estimates of benefits, expressed in dollars.

The theme developed in this study, the need to eliminate the problem of "unknown" targets, is a profound one that embraces many alternative solutions. It is necessary to stress that the simulated experiment which was conducted at NAFEC was limited to a choice between two levels of automation defined as ARTS III and manual. No other alternatives were considered. As a result, this study is silent concerning the effectiveness of any other alternatives. The problems and time involved in instituting changes in terminal procedures or separation standards are, likewise, unknown and not studied. However, the experiment demonstrated that conflicts resulting from the above interaction could be reduced with no changes whatever in current procedures and practices of terminal control. Moreover, changes in procedure, considerations of terminal control areas or other methods for separating aircraft, are not really alternatives to the introduction of ARTS III. An ironic conclusion of the study is that instead of it being more difficult to justify the installation of ARTS III at the less dense terminals, the installation of a technological (automation) solution to the problem of IFR x VFR interactions makes more sense at these terminals. ARTS III

is, probably, not a sufficient solution at the more dense terminals. This does not mean, necessarily, that ARTS IV or ARTS IX would be better. It means that a procedural change is, probably, needed to complement the improvements in equipment. The saturation point in the ability to display targets — the limits in beacon technology, computer capacity, character writing and the controller's ability to assimilate the information for the increased numbers of targets that are not "known" to him — will, undoubtedly, be a major problem requiring additional measuresto solve the problem of unknown aircraft at major terminals. ARTS III will allow for an interim solution, a breathing space, while these alternatives are sought. And the breathing space will be greatest at the less dense terminals. Therefore, a major implication of this study is that it is necessary to have a concerted commitment to the solution of the problem of IFR x VFR interactions. ARTS III is indicated as a feasible solution to this problem at those locations located in the third lot buy.

C. Highlights of the Test Results

The salient features of the experiment are summarized in Table 10. In the next section, D, a detailed discussion of those experimental results that are most critical to the study's conclusions will be presented. This section summarizes the highlights shown in Table 10.

1. The operations count -- the total number of arrivals and departures, index 3 -- handled by controllers did not differ significantly between the ARTS and manual systems.

This count did not differ as well between the two controller groups: certificated and trainee. The data for these groups were always analyzed separately. No pooling of results took place between groups in order to increase the likelihood of demonstrating statistical significance. However, where appropriate, inferences were made between groups, without attributing statistical significance, in order to provide additional information about how the competing systems control traffic.

II. <u>The time in system for arriving aircraft</u>, index 6 — measured from the time the aircraft enter the experiment from a "ghost" position, representing an en route control center adjacent to the terminal, until the final approach to the runway — was higher, to a marginally significant degree, ( $\alpha = 0.25$) for ARTS III.

The time in the terminal system for arriving aircraft, index 8 -- measured from the time of the handoff to the terminal controller until the final approach to the runway -- was higher to a more significant degree ( $\alpha = 0.10$) for ARTS III.

The above data for the time in system confirm that results were causally linked to differences in equipment. ARTS equipment has such features as an automatic handoff of control between the center and the terminal and an automatic handoff between sectors of a terminal. Therefore, based on the results shown for the time in system there is strong reason to believe that the observed differences between systems were not haphazard events but rather a confirmation of the fact that a valid experiment took place. For example, the separate indices measuring the time in system (numbers 6 and 8) both indicate that aircraft controlled by ARTS were in the system longer. But, the difference in these indices (6 minus 8) measures the time it takes to transfer control from the en route center

Table 10

Summary Highlights of Data

| Index | Description | L = Low Half<br>H = High Half<br>C = Combined Hour | Certificated Controllers: Averages Per Team: Manual | Certificated Controllers: Averages Per Team: ARTS | Certificated Controllers: α * | Noncertificated Controllers: Averages Per Team: Manual | Noncertificated Controllers: Averages Per Team: ARTS | Noncertificated Controllers: α * |
|---|---|---|---|---|---|---|---|---|
| 3 | Total No. Arrivals and Departures | C | 62.39 | 62.20 | | 64.67 | 64.72 | |
| 6 | Time in System (Secs) -- Arriving Aircraft | C | 976 | 1033 | .25 | 967 | 991 | |
| 8 | Time (Secs) in Terminal -- Arriving Aircraft | C | 703 | 769 | .10 | 712 | 770 | .05 |
| 6-8 | Acquisition Time (Secs) -- Arriving Aircraft | C | 274 | 264 | | 255 | 221 | .05 |
| 16 | Total Time (Secs) in Radio Communication | C | 1323 | 1170 | .05 | 1396 | 1346 | |
| 17 | Total Time (Secs) in Phone Communication | C | 731 | 274 | .01 | 786 | 206 | .01 |
| 20 | Total No. Requests for Reidentification | C | 3.17 | .61 | .01 | 5.72 | .17 | .05 |
| 23 | Total No. Requests for Altitude Verification | L | 23.22 | 6.22 | .05 | 13.06 | 3.39 | .01 |
| | | H | 24.61 | 7.83 | .05 | 16.72 | 6.56 | .05 |
| | | C | 47.83 | 14.06 | .05 | 29.78 | 9.94 | .01 |
| 26 | Total No. Directives for Steering Vectors | H | 67.33 | 73.44 | .25 | 77.72 | 84.61 | .10 |
| | | C | 114.33 | 110.72 | | 135.61 | 160.67 | .25 |
| 51 | No. IFR-VFR Separation Violations | L | .50 | .44 | | .06 | .06 | |
| | | H | 1.50 | 1.11 | .25 | 1.28 | 1.78 | .25 |
| | | C | 2.00 | 1.56 | .25 | 1.33 | 1.83 | .25 |
| 52 | No. IFR-IFR Separation Violations | L | .94 | .78 | | 1.28 | .78 | .10 |
| | | H | 4.06 | 3.46 | | 4.06 | 1.89 | .10 |
| | | C | 5.0 | 4.33 | | 5.33 | 2.67 | .05 |
| 54 | Time (Secs) IFR-VFR Violations | L | 64 | 32 | .25 | 10 | 16 | |
| | | H | 08 | 58 | .05 | 65 | 87 | |
| | | C | 149 | 90 | .05 | 75 | 101 | |
| 55 | Time (Secs) IFR-IFR Violations | L | 37 | 19 | .25 | 65 | 40 | .25 |
| | | H | 178 | 182 | | 354 | 142 | .10 |
| | | C | 214 | 201 | | 419 | 182 | .10 |
| 89 | Index of Orderliness | N.A. | 277 | 159 | .25 | 425 | 172 | |

* α = Level of statistical significance.

to the terminal; and this measure favors ARTS. Index (6 minus 8) is observed to be less for ARTS because this system uses equipment designed to provide an automatic handoff capability. For this same reason, it is argued that the indices measuring the time spent in communication (12 through 17) are lower to a statistically significant degree for the ARTS system because of physical differences in the equipment used. This is especially true of those indices measuring phone communications (index 17; $\alpha$ = .01). Again, ARTS employs an automatic handoff feature between terminal sectors, and less time is needed for controllers to coordinate these handoffs.

Indices 27-30 measure communications on a per aircraft basis, but the number of operations handled did not differ much between systems so that these differences, while statistically significant in favor of ARTS, merely confirm the pattern previously reported for indices 12 through 17.

Finally, in demonstrating that results are not likely to be random occurrences which are not related to inherent differences in the systems, the number of requests for altitude verification (index 23) and target reidentification (index 20) were significantly less for the ARTS system. ARTS equipment was designed to provide these reductions by its continued display of altitude information. The experime confirmed our expectations.

III. The experiment revealed that the use of ARTS III equipment is likely to result in a reduction in the number of violations of airspace (conflicts).

a) Index 52, the number of conflicts involving IFR x IFR aircraft were observed to be reduced for the certificated controller using ARTS. This reduction is indicated to be of great practical significance although not statistically significant at an $\alpha$ level of 0.25. A detailed discussion as well as a sample by sample comparison of results for this index will be provided below in section D.

This same index was significantly lower, in a statistical sense, for the non-certificated group of controllers ($\alpha$ = 0.05 for the combined hour). However, in keeping with the ground rules established for the study, no cross-pooling of results between groups took place. The finding of a statistically significant reduction in index 52, a sensitive measure of performance, was used only to infer in a qualitative way that certificated controllers could be expected to do better with ARTS; to improve by an amount equal to that shown for the trainee group after they had thrown off the inertia brought about by the habitual use of the older system. But, in addition, this finding indicated the possibility for a modest dollar benefit attributable to ARTS because of the demonstrated ability to reduce the time required to train controllers.

b) Index 54, "The Time in Conflict for IFR x VFR Aircraft," was observed to be significantly reduced for the certificated controller to a high degree of statistical significance ($\alpha$ = 0.05) for the half-hour of high activity as well as for the combined hour of traffic. Time in Conflict incorporates a measure of the severity of a violation in separation standards, and this finding was considered to be the most

important of the entire set of experimental results. The observed difference in this index meets all of the evaluation criteria we imposed. The difference: 1) was observed to take place while certificated controllers were operating the equipment, 2) was determined to be statistically significant, 3) is logically tenable and causally linked to differences in the equipment, and 4) is translatable into dollar benefits. This translation of an experimental finding into an estimate of dollar benefits is shown in section III below.

c) Index 55, The Time in Conflict for IFR x IFR Aircraft, indicates that the trainee group performed poorly with the manual system. Their rate of time in conflicts for the high half-hour of activity was an average of 708 seconds, (2 x 354), or 11.8 minutes out of each hour of active traffic. The finding that trainee controllers were in conflict approximately 20 percent of the time while using the manual system was taken to be another indication that reductions in the time to train controllers were possible with ARTS.

d) The comparison of the indices of orderliness was found to favor the ARTS system. This index was proposed in order to correct for anticipated deficiencies in conflict data. Midair collisions are rare events, and conflicts in airspace are not likely to occur with great frequency. After all, the entire system of control -- men, equipment and procedures -- is designed to prevent conflicts. This is decirable from everyone's point of view except the dispassionate analyst who cannot use his tools of analysis to discern patterns and differences in conflicts when the data are few. Previous experience with a simulation of the

Baltimore terminal area [7/] did not yield conflict data of sufficient accuracy and quantity to permit an objective judgment of results. For this reason, it was felt that a proxy measure should be used. This measure was designed to count all the instances in which there would be a conflict unless a controller intervened. This index predicted the future path of all targets under a controller's jurisdiction, and recorded all instances in which minimum standards of lateral and vertical airspace were violated. These instances were aggregated into a composite index with the use of a somewhat arbitrary weighting scheme to reflect the severity of the violation. It was felt that this would be analogous to measuring the comparative number of commands being given by, say, a traffic policemen at a busy intersection. It would be fruitless to compare the relative numbers of accidents or collisions at such intersections. But, it would be a meaningful comparison to record the numbers of commands that had to be given in order to provide for a safe intersection. In the same way, it was anticipated that actual conflicts in the terminal airspace would be rare, but the study intended to argue that a system which required fewer commands on the part of the controller in order to avoid conflicts would be a more "orderly" and, hence, a safer system than one which required a greater number of commands.

Index 89 is a composite index of orderliness for both the arrival and departure positions. It shows a statistically significant reduction in favor of ARTS ($\alpha = 0.25$).

7/ See Ref. 5.

Although it was anticipated that the demonstration of a favorable result in this index would provide a strong argument for ARTS, when the entire package of results was analyzed, it was discovered that this index was, indeed, an important measure, but for a different reason. For one thing, there was no lack of conflict data generated by the experiment. Unlike previous attempts at simulation, the equipment used in the present experiment was vastly superior in that, for the first time, traffic could be presented in digitized form with sufficient accuracy to enable conflicts to be measured directly. Because conflict data did appear in ample quantity to allow for statistical judgments to be made, there was now no urgent need to resort to a demonstration of differences in a substitute measure, the index of orderliness. But it was possible to reap other analytical benefits by attempting to establish the validity of this measure. A "spin-off" analysis was performed to relate this index to the conflict data in order to determine whether it measured some important facet of air traffic control, or whether, perhaps, it was merely an arbitrary measure that fluctuated at random?

Two separate pieces of evidence indicate that it is more reasonable to conclude that the index of orderliness is related to essential functions of air traffic control:

1) The investigations by the Transportation Systems Center [8/] demonstrate a very high correlation between this index and the number of conflicts.

8/ op. cit. Ref. 4.

2) At the end of the experiment, A. G. Halverson ranked the performance of all controller teams engaged in the simulated experiment solely on the basis of his index of orderliness. An independent ranking was also made of controller performance by D. O. Brown, the project manager for the NAFEC experiment. The rankings were almost identical.

With the evidence of statistical equivalence as well as indications of functional validity, it was decided to use the index of orderliness as a proxy for conflicts in subsequent analytical investigations of the probable causes for conflicts in terminal airspace. An instantaneous count of all targets on the radar scope was made at one minute intervals for the duration of the experiment. Since, in any given minute it is possible that no conflicts would occur, the analysis of these conflicts would require sophisticated mathematical manipulations. Statistical regression analyses which relate traffic characteristics to a dependent variable, Conflicts, for which zero values are possible, can be quite messy. Not so, when the index of orderliness is substituted as the variable. A detailed discussion of the subsequent investigations of the causes of conflicts, using the index of orderliness as a substitute measure of these conflicts is presented in Appendix A.

IV. The investigations into controller capacity indicated no statistically significant differences between systems. Alternative ways of defining capacity and estimating its dimension were tried. A detailed description of these efforts is provided in section D, below.

In general, attempts were made to estimate the comparative time it took each system to become overloaded and to go into "holding."

V. Analytical extrapolations of the experimental data were completed successfully and are reported in detail in Appendix A. In summary, these analytical investigations were performed to relate the observed number of conflicts to characteristics of the traffic sample: 1) the density of traffic by type: IFR; VFR; 2) the proportion of targets having transponders with Mode C capability. These investigations indicate that the number of unknown targets were a statistically significant variable contributing to conflicts and more importantly, that there was a statistically significant reduction due to ARTS in the number of conflicts associated with increasing levels of unknown traffic. In addition, these investigations indicate that the so-called "gas molecule" law which theorizes that conflicts will increase as the square of the number of airborne targets does not apply to the case in which these targets are under the discipline of an air traffic control system. Conflicts were observed to increase at a constant percentage of unity as IFR traffic increased; an exponent closer to 1.0; not 2.0. For these investigations, the number of conflicts were represented by the index of orderliness. However, the reliability of the results of this follow-on analytical effort is questionable, and will be discussed as a separate topic in Appendix A.

D. <u>Detailed Analysis of the Test Results</u>

In this section, a detailed discussion of results will be presented

of the following topics: a) Controller Capacity and b) Conflicts: A Measure of Safety.

a) Controller Capacity

If one could measure the rate at which inputs were coming into a system, and the rate at which they were leaving, it would be a simple matter to define the capacity of the [illegible] as the point at which the arrival rate exceeded the exit rate. In effect, this definition measures when a system "backs up," or in the case of terminal control when it goes into "holding;" "R," as defined below exceeds 1. But, these attempts performed by The MITRE Corporation were not successful. It seems that from the very first minute of the simulation, the rate of arriving aircraft exceeded the rate at which aircraft were exiting the system.

$$R = \frac{\text{rate of entry of aircraft}}{\text{rate of exit of aircraft}}$$

Another method was, therefore, tried in order to estimate the point at which each system reached its limit of capacity. Very simply, this method recorded the time the first "holding" instruction was given during each trial. The NAFEC team of observers were told to record this time in a format similar to Table 11.

> The idea is that it is possible to estimate the relative sizes of beer mugs by measuring the time that the pourer first stops filling the mug, and withdraws the bottle. This is not only a good estimate of the relative size of the mugs, but it

interacts with the pourer's estimate of this size; exactly what we want to measure.

In general, all controller teams issued their first instruction to hold after about 30 minutes of traffic buildup. It was hoped that a sample by sample comparison of the exact times the instruction was given would reveal a pattern sufficient for making an objective judgment regarding controller capacity.

Team I illustrates a pattern sufficient to conclude that the ARTS system became overloaded at a later point in time than the manual system, when confronted with the identical traffic sample. With sample A, team I issued their first "hold" instruction at 9:32.43 A.M. using the manual system; at 9:42.22 A.M. using ARTS. With sample B, this same team recorded times of 9:28.56 A.M. with manual; 9:37.47 A.M. with ARTS. With sample C, the times were 9:35.09 A.M. manual; 9:36.55 ARTS. With each sample, team I went into holding at a later time when using the ARTS system. The conclusion would follow that the ARTS system resulted in greater controller capacity, if this pattern were repeated for all teams or even a majority of the teams. But, the pattern for the other teams was too variable to draw any such conclusion. The average time that a "hold" instruction was first given for all teams was 9:32.18 for manual, 9:33.18 for ARTS. Again, this is inconclusive evidence of increased capacity.

Table 11

NAFEC CERTIFICATED CONTROLLERS

TIME AT WHICH CONTROLLERS SLOW OR STOP THE ARRIVAL FLOW

| TEAMS | MANUAL SYSTEM | | | | ARTS | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | | A | B | C |
| 1 | 09:32:43 | 09:28:56 | 09:35:09 | | 09:42:22 | 09:37:47 | 09:36:55 |
| 2 | 09:26:05 | 09:24:50 | 09:24:25 | | 09:16:29 | 09:28:14 | 09:23:12 |
| 3 | 09:30:56 | 09:26:33 | 09:26:08 | | 09:21:05 | 09:38:40 | 09:37:24 |
| 4 | 09:41:25 | 09:41:35 | 09:36:15 | | 09:39:00 | 09:33:42 | 09:42:03 |
| 5 | 09:34:00 | 09:38:19 | 09:25:15 | | 09:26:27 | 09:31:35 | 09:36:41 |
| 6 | 09:31:43 | 09:38:46 | 09:39:10 | | 09:33:40 | 09:38:33 | 09:35:29 |
| | | | | | | | |

However, it is interesting to note that on the 71st run out of a total of 72 in the experiment, the trainee controller working the arrival position did not issue a "hold" instruction during the entire hour while using ARTS. And, he did perform to the average of his group in the ability to avoid conflicts. But, this event was not repeated and is, therefore, an isolated example only of the potential for increased capacity available from ARTS.

There is a clear temptation to conclude, therefore, that based upon the experimental results there is no increase in controller capacity demonstrated by the ARTS system. But, this conclusion ignores the previous discussion concerning the difficulty in evaluating a multi-dimensional system. To draw conclusions in one dimension requires that the performance in all the other dimensions be held equal. However, this is not the case for the present evaluation of controller capacity. The number of conflicts were not equal. This is similar to an evaluation of a typist's performance based only on speed without a consideration of the number of mistakes that are made.

Figure 5 [9/] indicates the time each system was in a conflict of the IFR x VFR variety. This figure was devised to highlight differences in system safety, and it is introduced together with a detailed discussion in the section on "conflicts" offered below. But, this graph could just as readily be interpreted to indicate controller capacity by assuming some fixed time in conflict, and then comparing the levels of traffic handled by each system. For example, for the same value of two minutes in conflict, the ARTS system can, according to Figure 5, handle approximately 82 aircraft per hour; the manual system 67 per

9/ See page 81.

hour. The conclusion that there is either: 1) fewer conflicts, or 2) increased capacity is a matter of choice that depends on the particular facet of performance that the study wishes to highlight. In the same way, it can be argued that although the number of IFR targets on the controller's radar scope at any instant in time showed no difference in the number of targets being worked, the capacity of the ARTS system was, in reality, much greater. Both systems had an average of five VFR targets on the radar scope at every instant of time. To the manual system, however, these targets imparted little information, but these same targets equipped with Mode C transponders were providing the ARTS controller with additional relevant information that required his further action. In effect, then, the ARTS controller was working a total of 17 targets compared to the manual total of 12.

Figure A.1 [10/] was drawn in order to highlight the differences in the number of conflicts that result from the fact that the ARTS controller is, in reality, working with more targets known to him and is, therefore, able to perform with fewer conflicts. For example, for an identical value of 1.4 for the index of orderliness, the ARTS system can handle, at any instant, an increased number of unknown targets of the sample varieties included in the experiment: The manual system can handle 1.5 aircraft; the ARTS system, 4.5 aircraft.

It would, therefore, not be accurate or fair to conclude that there are no differences in controller capacity. The more reasonable conclusion

10/ See page 145, Appendix A.

is that the study chose to demonstrate differences in the most critical of the performance measures, safety. For this reason, the experiment was designed to uncover differences in conflicts, under controlled conditions. This compromised the ability to discover differences in other performance measures. If differences in controller capacity are considered to be of critical importance then it is recommended that a different experiment, one that has been designed to elicit these special differences, be performed.

b) Conflicts; A Measure of Safety

This section of the report deals with those findings designated as being of critical importance, prior to the conduct of the experiment. A detailed presentation of these results are shown in the following tables 12 through 15:

Certificated Controllers

| | | |
|---|---|---|
| Table 12 | Number of Conflicts (IFR x VFR) | Index 51 |
| | Number of Conflicts (IFR x IFR) | Index 52 |
| Table 13 | Time in Conflict (IFR x VFR) | Index 54 |
| | Time in Conflict (IFR x VFR) | Index 55 |

Noncertificated Controllers

| | | |
|---|---|---|
| Table 14 | Number of Conflicts (IFR x VFR) | Index 51 |
| | Number of Conflicts (IFR x IFR) | Index 52 |
| Table 15 | Time in Conflict (IFR x VFR) | Index 54 |
| | Time in Conflict (IFR x IFR) | Index 55 |

The above tables permit a sample by sample comparison (matched pairs of observations) for each team using the ARTS and manual systems.

> The statistical analyses of variance performed on these data attempted to determine whether the observed differences in conflicts could be explained as random variations, or were due to inherent differences in the systems themselves. In effect, the analyses made statistical adjustments to eliminate those differences due to: 1) variations in the three sample patterns of traffic, 2) variations in the six different teams of controllers, 3) variations in the interaction effects of specific controller teams operating with given samples of traffic. The remaining variation, or experimental error, was used to determine whether observed differences in system performance could be judged, objectively, to be due to some non-random effect. But, these analyses, although superior in statistical power, do not lend themselves to intuitive judgment and insight. The mind boggles in its attempt to do statistical analyses of variance. For this reason, a simple match-up of results is presented in order to provide some intuitive feelings for how the systems compare when the same team controls the identical traffic sample. These comparisons are amenable to objective judgments to any stated degree of statistical reliability, but, to repeat, the statistical power of these judgments are less than what is provided by the more sophisticated analyses of variance previously reported in Table 8A. However, the results shown in Table 8A are less informative than the direct match-up of observations. For illustrative purposes, then, the detailed comparisons of all the experimental data dealing with conflicts are shown in Tables 12 through 15.

Each (+) sign indicates that there were more violations under the manual system than ARTS; a (-) sign indicates the reverse: that ARTS had more violations than manual. A (0) indicates a tie score. The total of "(+; -; 0)" must add to 18 for each index. By comparing

Table 12

Indices 51; 52

NUMBER OF CONFLICTS

NAFEC Certificated Controllers
Sample by Sample Comparison
"Sign Test"

(18 matched comparisons)
Manual (M) vs. ARTS (A)

| | | 1st Half Hour | | | | | | 2nd Half Hour | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IFR-VFR | | | IFR-IFR | | | IFR-VFR | | | IFR-IFR | | |
| Team | Sample | Index 51 | | | Index 52 | | | Index 51 | | | Index 52 | | |
| | | (M) | (A) | Sign | (M) | (A) | Sign | (M) | (A) | Sign | (M) | (A) | Sign |
| 1 | a | 0 | 0 | 0 | 2 | 0 | + | 1 | 3 | - | 6 | 8 | - |
| | b | 0 | 0 | 0 | 3 | 2 | + | 2 | 2 | 0 | 3 | 6 | - |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | + | 8 | 8 | 0 |
| 2 | a | 2 | 0 | + | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| | b | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | - | 0 | 0 | 0 |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | + |
| 3 | a | 2 | 2 | 0 | 2 | 0 | + | 0 | 0 | 0 | 6 | 2 | + |
| | b | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 5 | 7 | - |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | + | 4 | 2 | + |
| 4 | a | 1 | 0 | + | 1 | 1 | 0 | 3 | 2 | + | 7 | 1 | + |
| | b | 0 | 2 | - | 1 | 5 | - | 2 | 2 | 0 | 4 | 4 | 0 |
| | c | 0 | 0 | 0 | 2 | 0 | + | 1 | 1 | 0 | 1 | 6 | - |
| 5 | a | 1 | 2 | - | 2 | 1 | + | 2 | 1 | + | 3 | 3 | 0 |
| | b | 1 | 1 | 0 | 0 | 2 | - | 2 | 0 | + | 2 | 2 | 0 |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | - |
| 6 | a | 1 | 0 | + | 1 | 0 | + | 4 | 1 | + | 6 | 3 | + |
| | b | 0 | 0 | 0 | 2 | 2 | 0 | 2 | 3 | - | 5 | 4 | + |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | + | 7 | 5 | + |
| Summary Totals | | | | 3+<br>2- | | | 6+<br>2- | | | 7+<br>3- | | | 7+<br>5- |

\+ = more conflicts under manual
\- = more conflicts under ARTS
0 = same number of conflicts

Table 13

Indices 54; 55

TIME IN CONFLICT (SECONDS)

NAFEC Certificated Controllers
Sample by Sample Comparison
"Sign Test"

(18 matched comparisons)
Manual (M) vs. ARTS (A)

| | | 1st Half Hour | | | | | | 2nd Half Hour | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IFR-VFR | | | IFR-IFR | | | IFR-VFR | | | IFR-IFR | | |
| Team | Sample | Index 54 | | | Index 55 | | | Index 54 | | | Index 55 | | |
| | | (M) | (A) | Sign | (M) | (A) | Sign | (M) | (A) | Sign | (M) | (A) | Sign |
| 1 | a | 0 | 0 | 0 | 48 | 0 | + | 57 | 124 | - | 389 | 417 | - |
| | b | 0 | 0 | 0 | 128 | 38 | + | 127 | 100 | + | 60 | 332 | - |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 172 | 140 | + | 382 | 404 | - |
| 2 | a | 310 | 0 | + | 0 | 0 | 0 | 0 | 0 | 0 | 170 | 42 | + |
| | b | 0 | 0 | 0 | 24 | 34 | - | 0 | 59 | - | 0 | 0 | 0 |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 102 | 0 | + |
| 3 | a | 208 | 220 | - | 74 | 0 | + | 0 | 0 | 0 | 305 | 128 | + |
| | b | 55 | 5 | + | 0 | 0 | 0 | 107 | 97 | + | 205 | 398 | - |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 78 | 0 | + | 116 | 91 | + |
| 4 | a | 41 | 0 | + | 14 | 24 | - | 155 | 95 | + | 195 | 23 | + |
| | b | 0 | 112 | - | 19 | 111 | - | 122 | 70 | + | 78 | 126 | - |
| | c | 0 | 0 | 0 | 34 | 0 | + | 125 | 61 | + | 22 | 239 | - |
| 5 | a | 265 | 195 | + | 228 | 26 | + | 102 | 41 | + | 100 | 225 | - |
| | b | 75 | 41 | + | 0 | 58 | - | 26 | 0 | + | 61 | 46 | + |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 61 | - |
| 6 | a | 202 | 0 | + | 51 | 0 | + | 255 | 58 | + | 186 | 167 | + |
| | b | 0 | 0 | 0 | 43 | 51 | - | 120 | 196 | - | 204 | 267 | - |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 0 | + | 589 | 314 | + |
| Summary Totals | | | | 6+ 2- | | | 6+ 5- | | | 11+ 3- | | | 8+ 9- |

+ = more time in conflict under manual
- = more time in conflict under ARTS

0 = same time in conflict

Table 14

Indices 51; 52

NUMBER OF CONFLICTS

Noncertificated Controllers
Sample by Sample Comparison
"Sign Test"

(18 matched comparisons)
Manual (M) vs. ARTS (A)

| Team | Sample | 1st Half Hour | | | | | | 2nd Half Hour | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IFR-VFR | | | IFR-IFR | | | IFR-VFR | | | IFR-IFR | | |
| | | Index 51 | | | Index 52 | | | Index 51 | | | Index 52 | | |
| | | (M) | (A) | Sign | (M) | (A) | Sign | (M) | (A) | Sign | (M) | (A) | Sign |
| 1 | a | 1 | 1 | 0 | 4 | 3 | + | 1 | 2 | - | 4 | 2 | + |
| | b | 0 | 0 | 0 | 1 | 0 | + | 0 | 0 | 0 | 8 | 1 | + |
| | c | 0 | 0 | 0 | 1 | 0 | + | 3 | 1 | + | 6 | 4 | + |
| 2 | a | 0 | 0 | 0 | 3 | 1 | + | 1 | 3 | - | 6 | 1 | + |
| | b | 0 | 0 | 0 | 2 | 2 | 0 | 1 | 1 | 0 | 4 | 2 | + |
| | c | 0 | 0 | 0 | 2 | 0 | + | 3 | 2 | + | 6 | 0 | + |
| 3 | a | 0 | 0 | 0 | 2 | 0 | + | 1 | 6 | - | 3 | 3 | 0 |
| | b | 0 | 0 | 0 | 3 | 1 | + | 2 | 2 | 0 | 1 | 3 | - |
| | c | 0 | 0 | 0 | 2 | 0 | + | 2 | 1 | + | 4 | 2 | + |
| 4 | a | 0 | 0 | 0 | 0 | 1 | - | 0 | 0 | 0 | 1 | 1 | 0 |
| | b | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | - | 3 | 2 | + |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 4 | 2 | + |
| 5 | a | 0 | 0 | 0 | 1 | 0 | + | 1 | 2 | - | 6 | 2 | + |
| | b | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 4 | 5 | - |
| | c | 0 | 0 | 0 | 0 | 1 | - | 0 | 1 | - | 10 | 3 | + |
| 6 | a | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | + |
| | b | 0 | 0 | 0 | 0 | 2 | - | 2 | 2 | 0 | 0 | 0 | 0 |
| | c | 0 | 0 | 0 | 0 | 1 | - | 2 | 3 | - | 2 | 1 | + |
| Summary Totals | | | | 0<br>0 | | | 9+<br>4- | | | 3+<br>7- | | | 13+<br>2- |

+ = more conflicts under manual
- = more conflicts under ARTS
0 = same number of conflicts

Table 15

Indices 54; 55

TIME IN CONFLICT (SECONDS)

Noncertificated Controllers
Sample by Sample Comparison
"Sign Test"

(18 matched comparisons)
Manual (M) vs. ARTS (A)

| Team | Sample | 1st Half Hour | | | | | | 2nd Half Hour | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IFR-VFR | | | IFR-IFR | | | IFR-VFR | | | IFR-IFR | | |
| | | Index 54 | | | Index 55 | | | Index 54 | | | Index 55 | | |
| | | (M) | (A) | Sign | (M) | (A) | Sign | (M) | (A) | Sign | (M) | (A) | Sign |
| 1 | a | 182 | 251 | - | 343 | 195 | + | 98 | 76 | - | 231 | 42 | + |
| | b | 0 | 0 | 0 | 78 | 0 | + | 0 | 0 | 0 | 576 | 118 | + |
| | c | 0 | 0 | 0 | 57 | 0 | + | 226 | 101 | + | 584 | 269 | + |
| 2 | a | 0 | 0 | 0 | 109 | 68 | + | 34 | 165 | - | 617 | 30 | + |
| | b | 0 | 0 | 0 | 224 | 14 | + | 15 | 64 | - | 462 | 65 | + |
| | c | 0 | 0 | 0 | 73 | 0 | + | 42 | 59 | - | 509 | 0 | + |
| 3 | a | 0 | 0 | 0 | 19 | 0 | + | 63 | 237 | - | 100 | 227 | - |
| | b | 0 | 0 | 0 | 90 | 28 | + | 92 | 98 | - | 129 | 205 | - |
| | c | 0 | 0 | 0 | 43 | 0 | + | 84 | 110 | - | 242 | 137 | + |
| 4 | a | 0 | 0 | 0 | 0 | 17 | - | 0 | 0 | 0 | 26 | 14 | + |
| | b | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 99 | - | 143 | 118 | + |
| | c | 0 | 0 | 0 | 0 | 0 | 0 | 109 | 77 | + | 806 | 97 | + |
| 5 | a | 0 | 0 | 0 | 60 | 0 | + | 44 | 126 | - | 777 | 403 | + |
| | b | 0 | 0 | 0 | 68 | 51 | + | 54 | 69 | - | 155 | 242 | - |
| | c | 0 | 0 | 0 | 0 | 80 | - | 0 | 52 | - | 813 | 586 | + |
| 6 | a | 0 | 0 | 0 | 3 | 11 | - | 44 | 21 | + | 17 | 0 | + |
| | b | 0 | 0 | 0 | 0 | 176 | - | 217 | 90 | + | 0 | 0 | 0 |
| | c | 0 | 0 | 0 | 0 | 77 | - | 38 | 126 | - | 188 | 18 | + |
| Summary Totals | | | | 1- | | | 11+ 5- | | | 4+ 12- | | | 14+ 3- |

\+ = more time in conflict under manual
\- = more time in conflict under ARTS
0 = same time in conflict

the test results and affixing the appropriate sign to the difference in results, we can compare summary totals:

Table 12 provides the details and "sign" comparison for the number of conflicts of both the IFR x IFR (index no. 52) and IFR x VFR (index no. 51) varieties committed by the NAFEC team of certificated controllers. Note that all cases favor ARTS. There were fewer direct comparisons in which ARTS yielded more numbers of conflicts than the manual system, for both halves of the hour and for both varieties of conflicts.

Table 13 which depicts the time each system was in conflict tells the story essential to the study and upon which the majority of the dollar benefits claimed for ARTS III rests. There is little difference in the ARTS and manual systems ability to do the primary job of separating IFR aircraft (index no. 55). The essential difference is that the ARTS system was able to provide additional safety in the separation of IFR x VFR aircraft (index no. 54) without changing any of today's standards and procedures for controlling aircraft in the terminal area.

In the opinion of the writer, this demonstration of reductions in conflicts -- measured in physical units, not dollars -- for certificated controllers using ARTS equipment, is sufficient to

justify its installation at the terminal locations identified in the third lot buy. 11/

Tables 14 and 15 are similar to Tables 12 and 13 except that the comparisons shown are for the trainee controller groups. Table 14;

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11/ This statement, of course, did not appear in the previous draft version of the study forwarded to the Office of the Secretary of Transportation and to the Office of Management and Budget; offices that, in conjunction with the Federal Aviation Administration, were charged with the responsibility of making a rational decision with regard to ARTS III. It has been more than a year since the recommendation of the FAA was confirmed and a decision made to exercise the option to purchase the remaining third lot of this equipment. There is no way of knowing what, if any, influence this study had on this decision. However, there is every reason to suppose that the decision in favor of ARTS was made on the basis of the "issues," and that the evidence in support of the argument that there was a likelihood of increased safety due to ARTS III was brought to the attention of the decision makers, and discussed in detail. The reason for the bold assertion made above concerning the superiority of ARTS equipment is to remind the reader that the same kinds of strong assertions, based in major part on subjective judgments only, had to have been made by those charged with making an appropriate decision regarding ARTS. Somehow, a delusion seems to have taken hold of the suppliers of analytical studies and their too willing customers that it is possible to make investment decisions solely on the basis of quantitative evidence gathered under the heady and objective banner of cost/benefit analysis. To this point we have not yet assigned dollar values to our study results and, therefore, have not yet entered the more highly subjective world of cost/benefit analyses. We have dealt only with objective data, but the reader is again reminded that despite the balanced experimental design, the statistical controls and the analyses of variance, subjective judgments were required at every critical juncture in the analysis. Quantitative studies of even the most elegant sort do not take the decision maker out of the loop. They merely define more narrowly the areas in which he must assert his prejudices.

index 52, confirms that the trainee controllers using ARTS were able to separate IFR x IFR aircraft to within the standard set by the certificated controller after a briefing session that included only four hours of instruction; just two hours were with hands on the ARTS simulator equipment. However, index 51 shown in Table 14 also indicates that the trainee did not do nearly as well in separating IFR x VFR traffic, using ARTS. This important category was the single indicator in which the trainee's performance did not match that of the certificated controller. Perhaps, this group was under greater stress. Somewhat surprisingly, there was no deterioration in the trainee group performance in: 1) operations count 2) controller capacity (as measured by the time a "holding" instruction was first given), 3) delays and time in system. But, the trainee group using ARTS evidently could not perform their ancillary job of vectoring aircraft, on a time available basis, in order to avoid conflicts with known VFR aircraft. More importantly, as Table 15, index 55 indicates, the trainee controller could not operate the manual system satisfactorily in the primary job of separating IFR traffic. Not only were there 14 trials out of 18 in which the ARTS system resulted in less time in conflict, but a simple arithmetic calculation reveals that the manual system was in conflict for a total of 6375 seconds during the second half-hour of the experiment (compared to 2571 for ARTS). This amounts to an average of 354 seconds for a trial period of 30 minutes (1800 seconds); a conflict rate of 20 percent. This unsatisfactory rate for the manual system compared

to a statistically significant reduced rate for ARTS, a rate comparable to that achieved by the certificated controller, provided the basis for the modest savings in training costs claimed for the ARTS system. These dollar benefits provided by the possibility for a reduction in training time can be disallowed, however, without having any appreciable effect on the study's conclusion to install ARTS at the 29 candidate terminal locations.

Figures 4-7 are graphical representations of these conflict data plotted against the hourly rates of airborne traffic generated in the experiment. The choice of the appropriate traffic level to relate to a given index of performance depends, of course, on the purpose of the illustration, and the question at hand. For example, when attempting to determine dollar benefits and costs, the appropriate traffic activity level to consider would be the average annual volume of traffic. If, however, the problem were one of establishing the criteria for system design, a more appropriate measure would be the peak levels to be handled by the system. On the other hand, for purposes of establishing the realism and validity of the simulated experiment, the more appropriate activity level would be the number of targets that were controlled at any instant of time. This latter measure of traffic activity provides an indication of the workload imposed on the controller, and is, in fact, used in this study for the purpose of evaluating the realism of the experiment; described below in section E.

Since a further and detailed use of the data for conflicts will be relied upon for the analysis of the costs and benefits of the candidate systems, these conflict data are graphically illustrated below in relation to hourly rates of traffic. These rates will be projected to average annual volumes when costs and benefits are estimated in section F.

The reader is reminded that these graphs were drawn on the basis of two points, determined by experiment, for each system: one point for each half hour period of the experiment: f) for first half; s) for second half; C) for combined hour. The dotted line connecting these points is a postulated relationship only.

Figure 4 - (index 52 for certificated controllers) shows the indicated difference in number of IFR conflicts, in favor of ARTS.

Figure 5 - (index 54 for certificated controllers) shows the statistically significant reduction in IFR x VFR time in conflict, in favor of ARTS.

Figure 6 - (index 52 for noncertificated controllers) shows the statistically significant reduction in number of IFR conflicts, in favor of ARTS.

Figure 7 - (index 55 for noncertificated controllers) shows the statistically significant reduction in IFR time in conflict, in favor of ARTS.

FIGURE 4

# NUMBER OF CONFLICTS-IFR/IFR-PER SIMULATED HOUR VS HOURLY IFR TRAFFIC

INDEX #52

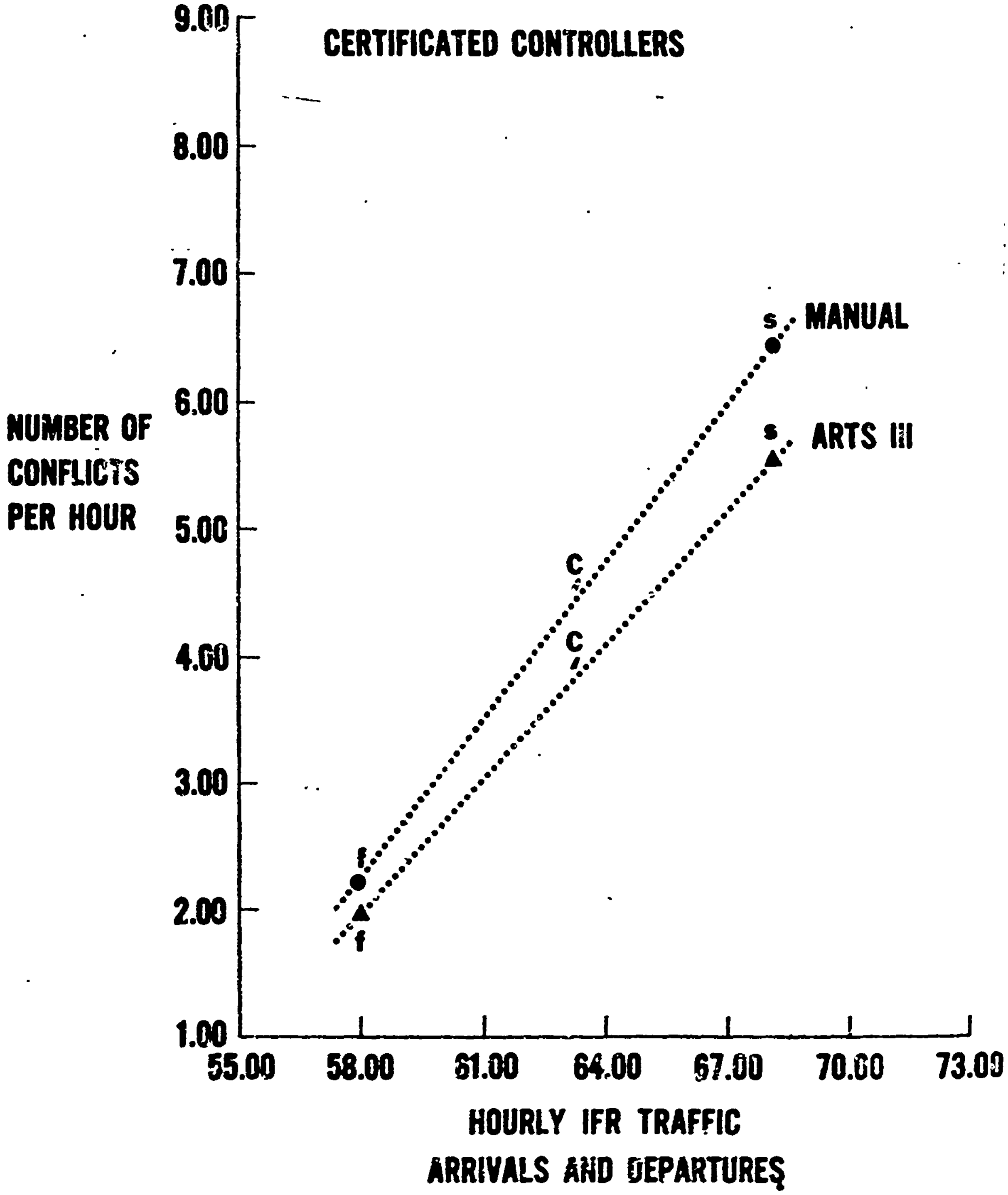


FIGURE 5

## TIME IN CONFLICT-IFR/VFR-MINUTES PER SIMULATION HOUR VS IFR + VFR HOURLY RATES OF TRAFFIC

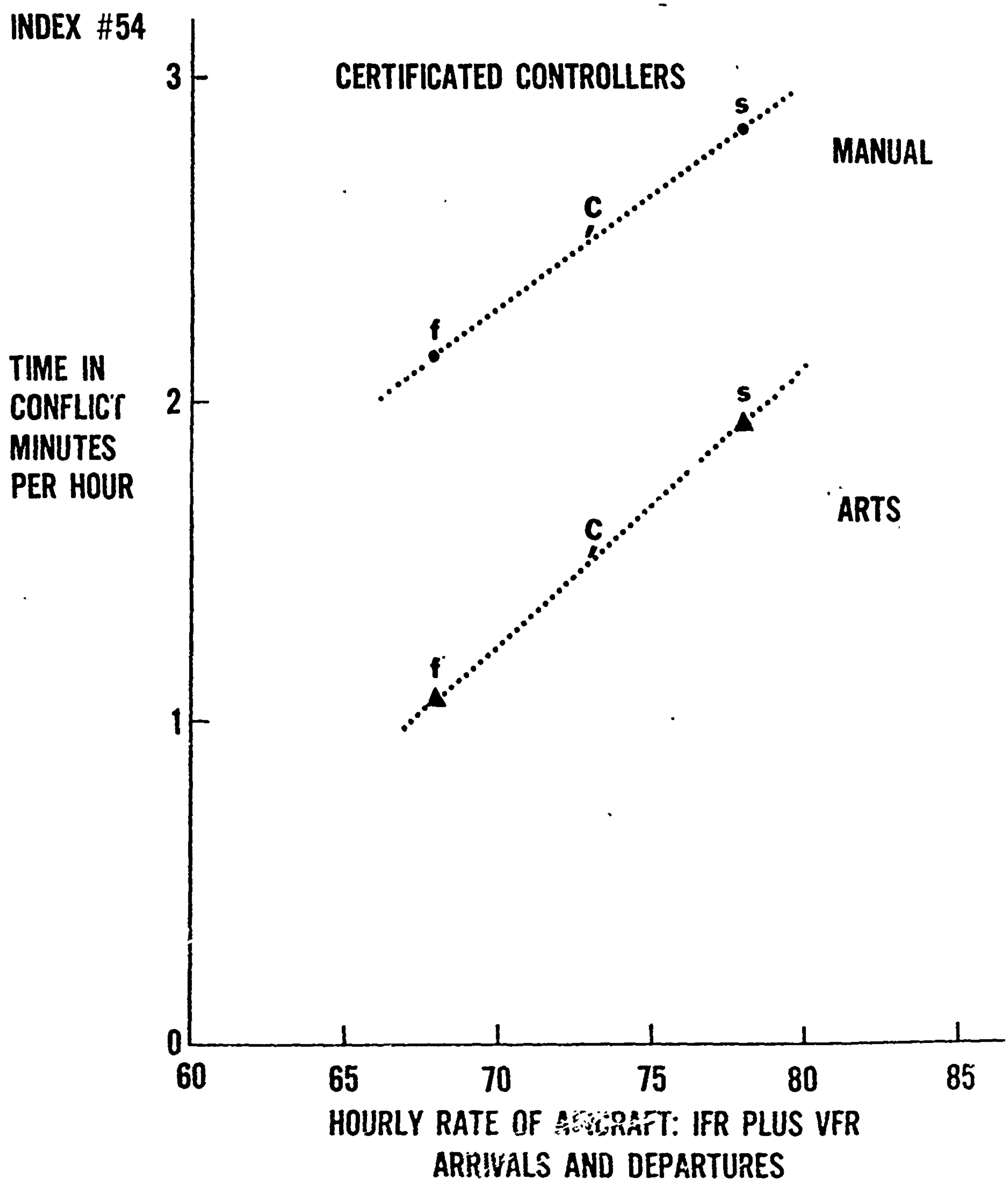


FIGURE 6

# NUMBER OF CONFLICTS -IFR/IFR- PER SIMULATED HOUR VS HOURLY IFR TRAFFIC

INDEX #52

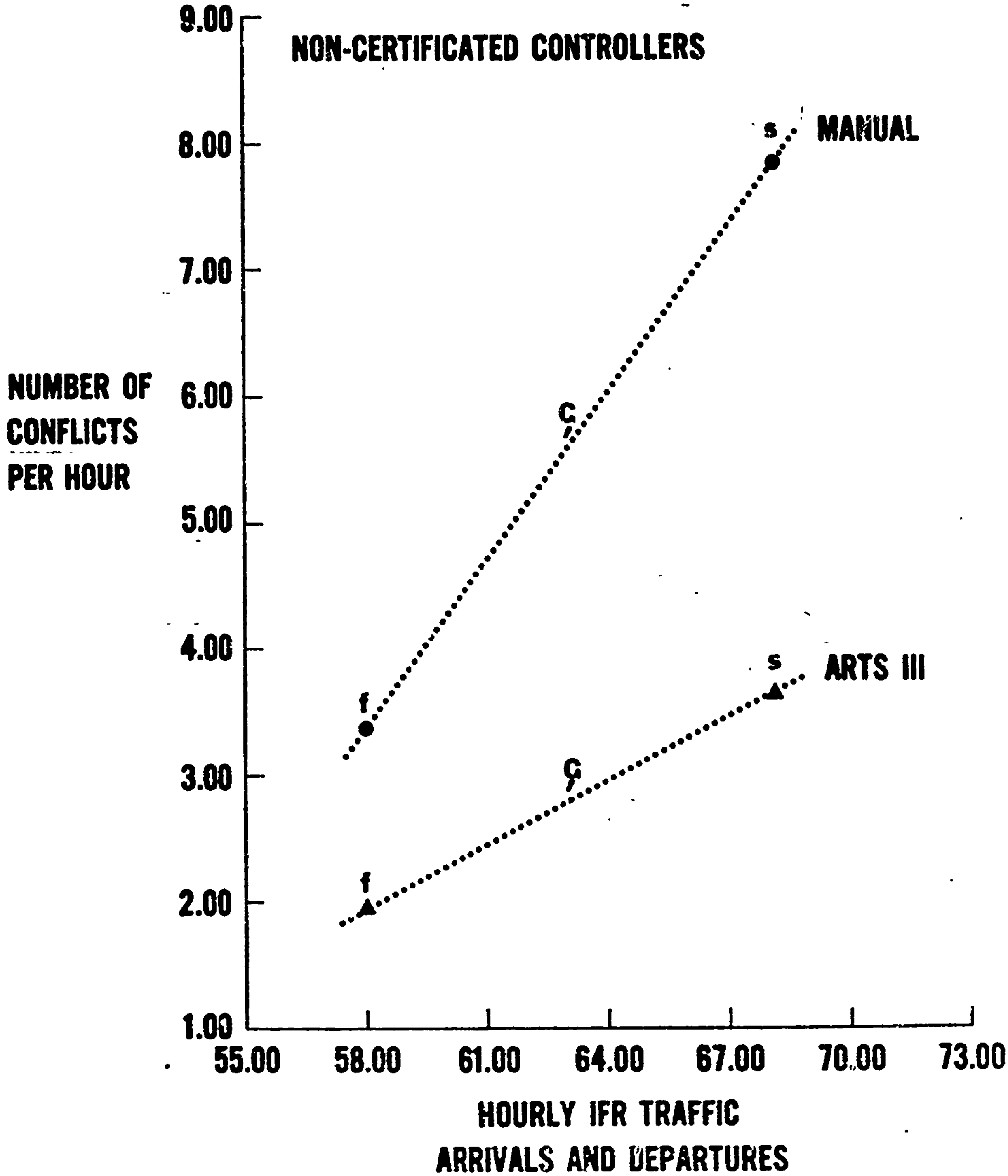
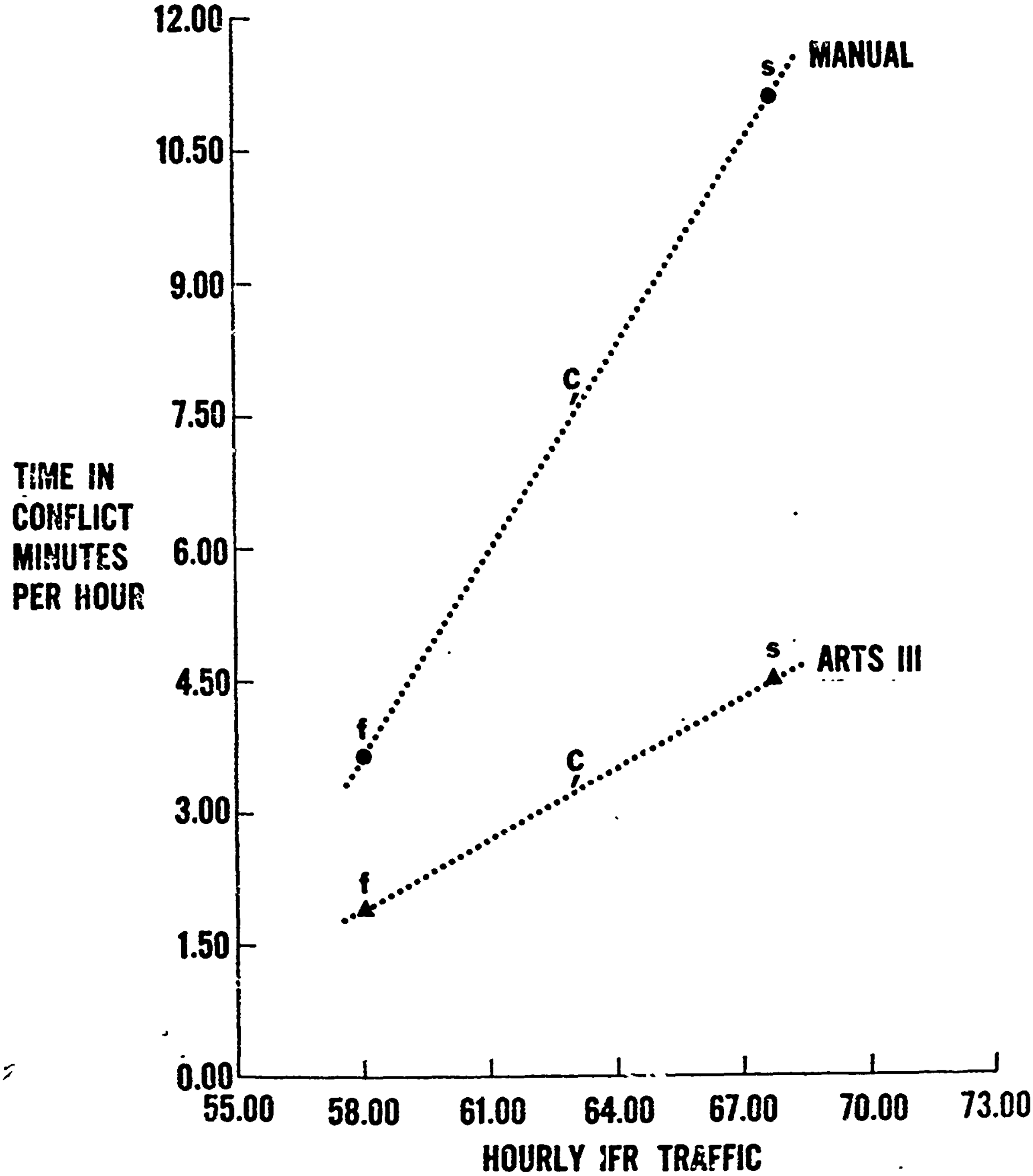


FIGURE 7

# TIME IN CONFLICT -IFR/IFR- MINUTES PER SIMULATION HOUR VS HOURLY IFR TRAFFIC

INDEX #55

NON-CERTIFICATED CONTROLLERS



## E. The Application of Test Results to the Real World

A critique of:

I. The Technique of Dynamic Simulations

II. The Traffic Sample

### I. Dynamic Simulations

An explicit study requirement was the determination of the criteria for installing ARTS. It was considered not sufficient to demonstrate that ARTS is a superior system. The conditions for which this superiority could be expected to hold had to be specified as well. These conditions, the criteria for installation, are usually defined by some measure of traffic activity. Study methods were limited, therefore, to those in which it was possible to balance and control patterns of traffic to any given level of activity. The only methods that qualify are those employing abstractions or simulations of reality. But, the resort to an abstraction of reality does not necessarily compromise the validity of a study. The statement that "reality is difficult to understand" is a platitude that doesn't bear repeating, but it is a relevant comment nonetheless. For example, a real world experiment took place at Knoxville, Tennessee, during the latter part of 1970. Its purpose was to compare the communications workload for the ARTS and manual systems. But, since traffic levels and other variables of reality could not be controlled, this experiment was not able to discern differences in these workloads; differences that were apparent at high levels of statistical significance from a dynamic simulation.

All study methods face the single and identical challenge of being able to predict results. There is no scientific responsibility to prove that an experimental setting is realistic. 12/ But, the dynamic simulation method of investigation is quite able to meet this superfluous challenge. By meeting this challenge it is hoped that we may increase the study's believability, if not its scientism.

Every effort was made to virtually reconstruct the setting of men and equipment in a typical terminal area. Mechanical devices, target displays and symbology were designed to be as close a representation of the actual systems as the art of dynamic simulations would allow. The anxiety and stress of controlling live traffic could not, of course, be duplicated, but the experiment was not free of stress and did not involve frivolous controllers working in a relaxed setting. Yet, the view persists that results obtained from dynamic simulations are "tainted" because they are derived from artifically created "play settings."

The world of quantitative analyses abounds in abstractions of reality based on regression analyses, computer generated simulations and other mathematical models with links to reality that are frequently more tenuous than those generated by attempts to simulate an environment. For some reason, one seldom sees a requirement imposed on these more usual and acceptable analytical techniques to verify their method. To

12/ For a discussion of this point see Friedman, "Essays in Positive Economics," Ref. 6.

repeat, the verification process consists solely of an examination of how well a study predicts results, but memory provides few examples of attempts by studies using "acceptable" techniques to confront their conclusions with data that were previously unavailable. However, this study will attempt to meet the challenge of verifying its method and its conclusions:

1) The most important single item of verification is the discovery of the increased probability of conflicts resulting from the mixing of known vs. unknown traffic. This problem area identified solely on the basis of the simulated experiment is very much in the news. William M. Flener, Director of the FAA's Air Traffic Service, called the problem of unknown aircraft the most important one facing today's air traffic control system. 13/ This same conclusion is contained in the Near Midair Collision Report of 1968. Moreover, Congressional Committees and other advisory groups have repeatedly drawn attention to this problem. 14/ The independent identification, but more importantly, the ability to quantify a problem that is subsequently discovered to be of critical concern to the FAA supports the contention that the simulated experiment was, indeed, realistic and valid.

13/ In his speech "Air Traffic Control of Today" delivered before the National Aviation System Planning Review Conference sponsored by the Department of Transportation, 1972.

14/ The Associated Press summary of the National Transportation Safety Board Report on Midair Collisions, released March 1971, is shown on the next page.

"181

AERIAL COLLISIONS

BY VERN HAUGLAND

WASHINGTON (AP)-THE NATIONAL TRANSPORTATION SAFETY BOARD, ALARMED AT THE NATION'S AERIAL COLLISION DEATH TOLL, URGED A SISTER AGENC. TODAY TO TIGHTEN PILOT-QUALIFICATION AND AIRCRAFT-EQUIPMENT RULES AND ACCELERATE TRAFFIC-SEPARATION PROCEDURES.

IN A BULKY REPORT ON A 1969 INQUIRY, THE SAFETY BOARD NOTED THAT OF 223 SKY COLLISIONS IN THE 10 YEARS THROUGH 1968 ABOUT HALF WERE FATAL AND CAUSED 528 DEATHS.

THE VAST MAJORITY OF THE COLLISIONS OCCURRED IN CLEAR WEATHER, THE BOARD SAID IN URGING CORRECTIVE ACTION BY THE FEDERAL AVIATION ADMINISTRATION.

ALTHOUGH 98 PER CENT OF THE COLLISIONS INVOLVED LIGHT PLANES, AND AIRLINE-TYPE PLANES WERE INVOLVED IN ONLY 6.7 PER CENT OF THE ACCIDENTS, THE OCCUPANTS OF THE AIRLINERS AMOUNTED FOR 66 PER CENT OF THE DEATHS, IT SAID.

IF THE ACCIDENT AND FATALITY RATES REMAIN THE SAME AND IF TRAFFIC INCREASES AT THE FORECAST RATE THE UNITED STATES MAY HAVE 335 ACCIDENTS AND 792 DEATHS IN THE NEXT 10 YEARS, THE BOARD SAID.

"NO ONE SOLUTION WILL ELIMINATE ALL MIDAIR COLLISIONS, BUT MUCH CAN BE DONE TODAY TO REDUCE OR ELIMINATE THE COLLISION POTENTIAL, THE BOARD REPORTED.

ACCORDINGLY, IT URGED THAT THE FAA ELIMINATE THE FREE MIXING OF "UNKNOWN" AND "KNOWN" TRAFFIC--PLANES OPERATING UNDER VISUAL FLIGHT RULES (VFR) AND THOSE OPERATING BY INSTRUMENTS (IFR)--ESPECIALLY IN TERMINAL AREAS.

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b) The project manager for the experiment, D. O. Brown of NAFEC, stated that he would have no hesitancy in certifying 16 out of the 18 trainee controllers who took part in the experiment. These controllers would have to be under proper supervision, but a distinct advantage of the ARTS system is that information essential to the supervisory function is readily displayed on the radar scope. The project manager's statement was used as part of the data confirming that training costs can be reduced, but for the purpose of the argument at hand it indicates that a controller can be judged on the basis of his performance with simulator equipment. Other controllers have confirmed that it is a relatively simple matter to tell whether someone knows his "stuff" by watching him perform in the simulated environment employed in the present experiment.

c) The prediction that training costs could be reduced with ARTS was confirmed by an unsolicited statement made at a recent meeting of the Air Traffic Controllers Association. 15/

d) Finally, the results of the simulation were discussed with both the New York (Common IFR Room) and Atlanta facilities. Judging by the "we told you so's" one wonders why we needed to do the experiment. (To quantify their impressions, of course). Statements

15/ M. Flowers, a controller at the Atlanta terminal facility, remarked that her facility found that it is easier to train controllers with ARTS. This remark was made during a question and answer session of a panel discussion of ARTS III equipment sponsored by the Air Traffic Controllers Association in Denver, Colorado, October 1971. The training supervisor at the Atlanta facility confirmed these remarks.

made by these facilities, and reported by the National Bureau of Standards 16/ about the ability to train controllers more easily using ARTS and the ability to reduce communications workload were confirmed by the simulated experiment. Statements concerning increased terminal capacity made by individual controllers at Atlanta and again reported by NBS in an independent study were not confirmed, however. But, both of the above named terminals, New York and Atlanta, employ levels of automation in excess of ARTS III.

In summary, the dynamic simulation employed was able to: 1) define the criteria of installation because it could statistically control for levels of traffic activity; 2) quantity differences in system performance that were not discernable from real world data that could not be balanced experimentally or controlled statistically; 3) demonstrate that it is capable of predicting and, thus, being verified by results in the real world.

It is reasonable to conclude, therefore, that the simulated environment of men and equipment employed at NAFEC provided a valid analytical method for comparing the candidate systems of air traffic control. And, like all methods of analyses, its use is limited to those investigations for which its validity can be established.

16/ "An Assessment of the Benefits of ARTS Based on Controller Experience at Atlanta and New York," see Ref. 7.

## II. The Traffic Sample

Another important consideration in deciding whether the results from the simulated world can be transferred to the real world is a comparison of the level of traffic activity. Were the aircraft types and traffic densities employed in the simulation comparable to the levels that might be expected realistically?

The measure of traffic activity appropriate to the question of whether results from a simulation are applicable to the real world is the number of targets that must be controlled at any instant in time. Reliable statistics for this measure of activity are not published in a form that categorizes aircraft sufficiently for our purposes. And a direct census of those terminals included in the third lot buy of ARTS III equipment had to be made. Letters were sent to six of these terminals, selected at random, asking for a determination of the peak number of targets appearing on their radar scope during the busy hour of the week in which the letter was received. In addition, these terminals were asked to further identify these targets as "known" or "unknown" according to the following definition:

Known aircraft targets are those in which spatial information in three dimensions is available. Aircraft which conform, in general, to this definition include,

a) All IFR aircraft; arrivals and departures

b) All IFR aircraft "overs" under positive control

c) All VFR aircraft in visual contact and under tower control

Unknown, all others including

d) VFR aircraft not under visual surveillance of tower

e) IFR "high overs"; not under positive control of terminal.

The sum of categories a) through e) represents the total radar contacts reported. These are shown in Table 16. Data for the years 1965-1970 are from published FAA sources, and are not categorized according to "known" and "unknown." Data for the year 1971 are the responses to the direct inquiry made to six candidate terminals.

Table 16 reveals that an average of 58 targets were counted on the radar scopes of the six terminals during some busy instant in the week of March 8, 1971. Of this number, 63 percent were unknown.

Table 16

PEAK INSTANTANEOUS RADAR COUNT AT SIX CANDIDATE TERMINALS

| | Total Radar Count 1/ | | | | | | 1971 Survey 2/ | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 1/ | Known | Unknown | Total |
| 1. Albany | 48 | 45 | 61 | 64 | 65 | 66 | 17 | 30 | 47 |
| 2. Buffalo | 58 | 55 | 56 | 62 | 70 | 94 | 20 | 65 | 85 |
| 3. El Paso | 22 | 17 | 24 | 42 | 58 | 52 | 13 | 34 | 47 |
| 4. Portland, Ore. | 64 | 59 | 87 | 74 | 71 | 63 | 39 | 41 | 80 |
| 5. Des Moines | 40 | 53 | 48 | 43 | 54 | 44 | 25 | 30 | 55 |
| 6. Tampa | 63 | 56 | 57 | 65 | 68 | 60 | 27 | 45 | 72 |

$\frac{\%\ \text{Known}}{\text{Total}} = 37$

SOURCE:
1/ Airport Activity: Peak Day; Busy Hour, FAA, 1970.
2/ Response to letter, March 8, 1971.

Table 17 depicts the world of simulation. In this world, two systems of air traffic control were operating. There is, therefore, a distinction between "knowns" and "unknowns" according to the system in use:

ARTS: <u>Known</u> consist of,

a) All IFR aircraft. There were no IFR "overs" or VFR operations (takeoffs or landings) in the simulation

b) All VFR overs with Mode C.

Therefore, unknowns are all VFR without Mode C.

Manual: <u>Known</u> consist of,

a) All IFR aircraft

Therefore, unknowns are all VFR aircraft.

Table 17

PEAK INSTANTANEOUS RADAR COUNT FOR SIMULATED TERMINAL

| | IFR | VFR | ARTS | | MANUAL |
|---|---|---|---|---|---|
| Arrivals | 9 | -- | Known | 9 | 9 |
| Departures | 3 | -- | | 3 | 3 |
| Overs | -- | 7* | | 5 | 0 |
| | | | Total Known: | 18 | 12 |
| | | | Grand Total: | 19 | 19 |

*All VFR aircraft were programmed to be transponder equipped. 80 percent of these VFR aircraft were programmed to have Mode C transponders.

It is evident from Table 17 that the possibility for conflicts is much less in the simulated world: 13 simulated airborne targets compared to a peak realistic level of 58 instantaneous targets. However, in several oral presentations made of this study, there was some criticism voiced over the fact that all VFR aircraft in the simulated exercise were programmed to have transponders; an average of 6 aircraft each instant. And, 80 percent of the transponders had Mode C capability. In effect, the study was criticized because it employed traffic samples that were not realistic. The present fleet of aircraft are not equipped with this high a proportion of transponders. This criticism is not well founded, however, and the following arguments are offered to support this contention:

An ARTS system consists of complementary components, on the ground and in the air, capable of automatically generating a block of data on the controller's radar scope. An airborne transponder is an integral part of the ARTS system. Any conflict which results while ARTS is controlling traffic cannot, therefore, be considered as an ARTS conflict unless the aircraft involved had an airborne transponder.

A plausible alternative would have been to use a traffic sample which had, say, 50 percent of the VFR aircraft equipped with transponders, or some other number that represented a realistic forecast of airborne traffic. Such a forecast was used to estimate the proportion of transponder equipped IFR traffic employed in the simulation. This forecast depends, of course, on the FAA's policy regarding transponders. Presently, at specified terminal locations where the Terminal Control

Area concept is in use, 100 percent of the aircraft using these terminals must be transponder equipped. But, the adjusting of the proportion assumed for transponder in order to agree realistically with some given forecast would not add to the study's validity. The purpose of any study is to learn something, and the experiment was designed to provide the maximum amount of information for a given number of trial observations. We would, undoubtedly, learn very little if one half of the time the ARTS system's ability to convert unknown traffic into known was limited by the fact that it was operating in a manner that was identical to the manual system. There is no difference between systems if there is no airborne transponder transmitting data that can be displayed automatically on a radar scope. Had it been suggested that all conflicts involving non-transponder equipped aircraft be deleted from the ARTS account or transferred to the manual account there, probably, would have been no criticism voiced. However, it was the announced intention of the study not to alter any data generated by the experiment. But, if such a transfer of data were allowed, the result would be that only those conflicts involving aircraft with transponders were being attributed to ARTS. In effect, this is precisely what was accomplished by a prior programming of the traffic sample. An 80 percent proportion of Mode C transponders was used in the hope that some additional analytical insight would result. If 100 percent of the aircraft had transponders capable of being tracked and displaying ground speed and only 80 percent of these were capable of providing altitude information, it was thought

that some basis could be developed for deciding which of the several features of ARTS III automation were most effective in reducing conflicts. This information is not essential to the present evaluation which was designed to compare the total ARTS III package of automation with the manual package. But, it was anticipated that subsequent studies might be required in the near future in order to decide on the most effective features of automation to purchase for installation at the smaller sized terminals. The evidence concerning the features that contribute most to conflict reduction is not clear and is reported elsewhere (Appendix A). What is clear is that ARTS as a total system of automation was able to demonstrate fewer conflicts for traffic samples that differed, on the average, by as few as five unknown aircraft. The relevant yardstick for judging the comparability of the ARTS vs. the simulated world is, therefore, not the percentage of aircraft that had transponders, but, rather, the probability that as many as five unknown or VFR aircraft could be expected at any instant on the radar scope of a candidate ARTS III terminal. Table 16 indicates that this probability is quite high. At the instant shown, there was an average of 41 unknown aircraft at all of the candidate locations at which measurements were taken. The conclusion is drawn that from the view of both total numbers of instantaneous airborne targets, and numbers of unknown targets, the simulated world employed traffic levels which were well below those encountered in the real world. Any results which depend on the level of traffic activity used in the simulation are, therefore, likely to occur realistically.

Tables 16 and 17, which compare total numbers of known and unknown aircraft within the terminal area also suggest that the current criteria for installing ARTS equipment be modified. The measure of traffic activity that is more appropriate to estimating the probability of a midair collision is the total number of aircraft within the terminal area, and not merely the number of operations at the primary terminal. For this reason, Table 18 has been amended to include itinerant operations at all secondary airports having control towers within the jurisdiction of the primary airport. This table was used in the subsequent estimation of costs and benefits attributable to ARTS III. Despite the marked increased activity over the numbers previously shown for operations at the primary airport only, shown in Table 2, Table 18 still understates the measure of activity that is most appropriate to a determination of the likelihood of a midair collision, i.e., the total number of aircraft that traverse the terminal airspace.

The activity levels shown in Table 18 are an understatement because they do not include: 1) military operations at military bases within the jurisdiction of the primary terminal; 2) operations at secondary airports without control towers; 3) aircraft which are flying through the terminal zone and which do not originate or terminate as an operation at either the primary airport or at any of the secondary airports within the terminal area; 4) all local traffic.

Table 18

ACTUAL AND FORECAST ITINERANT TRAFFIC AT PRIMARY AND SECONDARY AIRPORTS
WITHIN JURISDICTION OF THE PROPOSED ARTS III LOCATIONS (3RD LOT PROCUREMENT)

| Hub / Airport | FY 1970 IFR | FY 1970 VFR | FY 1970 Total | FY 1970 % Air Carrier Total IFR | FY 1977 IFR | FY 1977 VFR | FY 1977 Total | FY 1977 % Air Carrier Total IFR |
|---|---|---|---|---|---|---|---|---|
| Tampa | | | | | | | | |
| Tampa Int'l * | 146,797 | 46,280 | | | 197,300 | 50,700 | | |
| Sarasota Bradenton | -- | 65,273 | | | -- | 113,200 | | |
| St. Petersburg Int'l | -- | 74,480 | | | -- | 189,000 | | |
| St. Petersburg Whitten | -- | 40,117 | | | -- | 93,300 | | |
| Total | 146,797 | 226,150 | 372,947 | .611 | 197,800 | 446,200 | 643,200 | .571 |
| Baltimore (Friendship Int'l) | 132,285 | 100,520 | 232,805 | .798 | 199,100 | 74,800 | 273,900 | .761 |
| Portland, Ore. | | | | | | | | |
| Portland | 124,176 | 47,380 | | | 161,700 | 48,300 | | |
| Hillsboro | -- | 50,074 | | | -- | 88,000 | | |
| Total | 124,176 | 97,454 | 221,630 | .720 | 161,700 | 136,300 | 298,000 | .659 |
| Orlando | | | | | | | | |
| Orlando (Herndon) | 97,427 | 98,003 | | | 160,400 | 191,900 | | |
| McCoy AFB | -- | 21,656 | | | -- | 18,900 | | |
| Total | 97,427 | 119,659 | 217,086 | .374 | 160,400 | 210,800 | 371,200 | .241 |
| Dayton | | | | | | | | |
| Wright-Patterson AFB | 146,711 | 53,564 | | | 208,700 | 29,800 | | |
| Dayton Mun. | -- | 76,901 | | | -- | 93,900 | | |
| Clinton Co. AFB | -- | 30,962 | | | -- | 27,100 | | |
| Total | 146,711 | 161,427 | 308,138 | .441 | 208,700 | 150,800 | 359,500 | .453 |
| Omaha | | | | | | | | |
| Offutt AFB | 91,951 | 31,633 | | | 130,800 | 11,700 | | |
| Omaha | -- | 90,610 | | | -- | 88,000 | | |
| Total | 91,951 | 122,243 | 214,194 | .440 | 130,800 | 99,700 | 230,500 | .386 |

*IFR totals shown for the primary airport includes IFR traffic at secondary airports.

(Cont'd)

Table 18 (Cont'd)

ACTUAL AND FORECAST ITINERANT TRAFFIC AT PRIMARY AND SECONDARY AIRPORTS
WITHIN JURISDICTION OF THE PROPOSED ARTS III LOCATIONS (3RD LOT PROCUREMENT)

| Hub / Airport | FY 1970 IFR | FY 1970 VFR | FY 1970 Total | FY 1970 % Air Carrier Total IFR | FY 1977 IFR | FY 1977 VFR | FY 1977 Total | FY 1977 % Air Carrier Total IFR |
|---|---|---|---|---|---|---|---|---|
| Nashville | 103,878 | 66,306 | 170,184 | .585 | 127,100 | 78,200 | 205,300 | .549 |
| Jacksonville (Int'l) | 126,716 | 12,138 | 138,854 | .379 | 157,000 | 20,700 | 177,700 | .376 |
| Louisville | | | | | | | | |
| Standiford | 114,532 | 29,008 | | | 149,300 | 17,200 | | |
| Bowman | -- | 114,557 | | | -- | 281,000 | | |
| Total | 114,532 | 143,565 | 258,097 | .649 | 149,300 | 298,200 | 447,500 | .602 |
| Birmingham (Mun.) | 101,454 | 64,819 | 166,273 | .521 | 133,400 | 69,800 | 203,200 | .465 |
| Hartfort (Bradley Int'l) | 106,085 | 35,621 | 141,706 | .573 | 136,400 | 45,200 | 181,600 | .519 |
| Salt Lake City | 95,316 | 108,487 | 203,803 | .661 | 131,300 | 113,000 | 244,300 | .628 |
| Rochester | 85,260 | 47,257 | 132,517 | .665 | 106,800 | 46,300 | 153,100 | .622 |
| Syracuse | 88,761 | 33,157 | 121,918 | .679 | 106,100 | 29,000 | 135,100 | .594 |
| Tulsa | | | | | | | | |
| Tulsa Int'l | 88,314 | 77,084 | | | 122,200 | 78,800 | | |
| Tulsa Riverside | -- | 102,817 | | | -- | 199,200 | | |
| Total | 88,314 | 179,901 | 268,215 | .511 | 122,200 | 278,000 | 400,200 | .514 |
| Albuquerque | 75,252 | 98,799 | 174,051 | .535 | 93,500 | 118,500 | 212,000 | .528 |
| Providence | | | | | | | | |
| Quonset Pt. NAS | 79,428 | 20,000 | | | 113,000 | 17,500 | | |
| Providence | -- | 95,146 | | | -- | 106,300 | | |
| New Bedford | -- | 38,482 | | | -- | 79,000 | | |
| Total | 79,428 | 153,628 | 233,056 | .449 | 113,000 | 202,800 | 315,800 | .385 |

(Cont'd)

Table 18 (Cont'd)

ACTUAL AND FORECAST ITINERANT TRAFFIC AT PRIMARY AND SECONDARY AIRPORTS
WITHIN JURISDICTION OF THE PROPOSED ARTS III LOCATIONS (3RD LOT PROCUREMENT)

| | FY 1970 | | | | FY 1977 | | | |
|---|---|---|---|---|---|---|---|---|
| Hub / Airport | IFR | VFR | Total | % Air Carrier Total IFR | IFR | VFR | Total | % Air Carrier Total IFR |
| El Paso | | | | | | | | |
| El Paso Int'l | 64,128 | 91,994 | | | 80,000 | 92,000 | | |
| Biggs AAF | -- | 1,338 | | | -- | 1,200 | | |
| Total | 64,128 | 93,332 | 172,760 | .560 | 80,000 | 93,200 | 173,200 | .525 |
| Tucson | | | | | | | | |
| Davis-Monthan AFB | 92,320 | 133,168 | | | 131,400 | 104,600 | | |
| Tucson Int'l | -- | 76,243 | | | -- | 86,000 | | |
| Total | 92,320 | 209,411 | 301,731 | .357 | 131,400 | 190,600 | 322,000 | .316 |
| Shreveport | | | | | | | | |
| Greater Shreveport | 96,317 | 11,163 | | | 175,800 | 26,500 | | |
| Downtown Shreveport | -- | 57,040 | | | -- | 88,700 | | |
| Barksdale AFB | -- | 62,695 | | | -- | 54,900 | | |
| Total | 96,317 | 130,898 | 227,215 | .362 | 175,800 | 170,100 | 345,900 | .260 |
| Charlotte | 79,021 | 76,039 | 155,060 | .728 | 107,700 | 88,900 | 196,600 | .656 |
| Indianapolis (Weir-Cook) | 116,215 | 70,022 | 217,237 | .681 | 149,200 | 39,100 | 188,300 | .710 |
| Burbank | | | | | | | | |
| Burbank | 112,287 | 91,677 | | | 196,600 | 201,900 | | |
| Van Nuys | -- | 299,609 | | | -- | 605,200 | | |
| Palmdale | -- | 29,225 | | | -- | 61,600 | | |
| Total | 112,687 | 420,511 | 532,798 | .272 | 196,600 | 868,700 | 1,065,300 | .305 |
| Buffalo | | | | | | | | |
| Buffalo | 108,832 | 41,432 | | | 130,900 | 40,200 | | |
| Niagara Falls | -- | 61,166 | | | -- | 169,100 | | |
| Total | 108,832 | 102,598 | 211,430 | .729 | 130,900 | 209,300 | 340,200 | .679 |

(Cont'd)

Table 18 (Cont'd)

ACTUAL AND FORECAST ITINERANT TRAFFIC AT PRIMARY AND SECONDARY AIRPORTS WITHIN JURISDICTION OF THE PROPOSED ARTS III LOCATIONS (3RD LOT PROCUREMENT)

| Hub / Airport | FY 1970 IFR | FY 1970 VFR | FY 1970 Total | FY 1970 % Air Carrier Total IFR | FY 1977 IFR | FY 1977 VFR | FY 1977 Total | FY 1977 % Air Carrier Total IFR |
|---|---|---|---|---|---|---|---|---|
| Riverside | | | | | | | | |
| March AFB | 159,712 | 34,316 | | | 227,200 | 14,000 | | |
| La Verne | -- | 94,279 | | | -- | 216,800 | | |
| Ontario | -- | 58,394 | | | -- | 170,600 | | |
| Riverside Mun. | -- | 62,160 | | | -- | 172,600 | | |
| Total | 159,712 | 249,149 | 408,861 | .212 | 227,200 | 574,000 | 801,200 | .154 |
| Raleigh/Durham | | | | | | | | |
| Raleigh/Durham | 104,482 | 55,955 | | | 155,000 | 56,600 | 211,600 | |
| Ft. Bragg | -- | -- | | | -- | -- | | |
| Total | 104,482 | 55,955 | 160,437 | .445 | 155,000 | 56,600 | 211,600 | .421 |
| Sacramento | | | | | | | | |
| McClellan AFB | 181,636 | 47,198 | | | 258,400 | 29,800 | | |
| Sacramento Metro. | -- | 17,233 | | | -- | 30,600 | | |
| Sacramento Mun. | -- | 122,290 | | | -- | 204,700 | | |
| Total | 181,636 | 186,721 | 368,357 | .265 | 258,400 | 265,100 | 523,500 | .245 |
| Des Moines | 54,285 | 72,926 | 127,211 | .602 | 77,600 | 74,700 | 152,300 | .591 |
| Milwaukee | | | | | | | | |
| Milwaukee Mitch. | 118,690 | 71,305 | | | 153,700 | 78,500 | | |
| Milwaukee Tinn. | -- | 57,399 | | | -- | 101,900 | | |
| Total | 118,690 | 128,704 | 247,394 | .650 | 153,700 | 180,400 | 334,100 | .574 |
| Norfold (2nd lot buy location) | | | | | | | | |
| Norfolk | 134,142 | 50,211 | | | 168,800 | 51,800 | | |
| Newport News | -- | 44,984 | | | -- | 90,200 | | |
| Total | 134,142 | 95,195 | 229,337 | .449 | 168,800 | 142,000 | 310,800 | .468 |

SOURCE: FAA Air Traffic Activity Report FY 1970 and Military Air Traffic Activity Report FY 1969.
Forecasted activity supplied by Office of Aviation Economics, EC-200.

F. COST/BENEFIT ANALYSIS

> Rationale: If one had an estimate of the costs required to purchase a new option, and he had a dollar measure of the benefits they were expected to provide, a simple choice mechanism would be to purchase the option if the benefits were any amount greater than the costs. Notice that the extent of the bargain -- the excess of benefits over costs -- does not enter into the choice. This mechanism for choosing is sufficient for the decision at hand, one which is limited to a choice between two competing systems: ARTS and manual. It is not a sufficient mechanism, however, for deciding whether some other expenditure might not be more rational for the FAA. It cannot, for example, be used to decide whether it is better to invest in the construction of improved runways, or in new ways to maintain navigational facilities, etc. Nor can this rationale be used to decide whether the Nation were better off in investing in welfare reform, better schools, cancer research, or farm subsidies. These decisions are left to others.

In the preceding sections the difficulties in ascribing dollar benefits to a new system designed to perform a complex job were discussed. The usual, but important, problems of attributing dollars to such items as 1) lower variability in controller performance or, 2) the identification of emergency situations were cited as examples. Moreover, the problems associated with the double counting of benefits was, likewise, discussed. There were some 80 different indices used in this study, all intending to measure a different dimension of the controller's job, but many were probably redundant reflections of the very same facet of this job. However, this latter difficulty is frequently regarded as more of a loophole, than a problem. If, for example, there were an infinite number of beneficial attributes associated with a system, then it would be possible to justify the most expensive of systems, merely by assigning the modest estimate of one dollar per attribute. Is it any wonder then why many research companies being paid to perform cost/benefit analyses

stay up late at night thinking up more attributes, or new names for old ones? There is, of course, a need to close this loophole by imposing a strict discipline upon the number of attributes for which dollar benefits can be claimed: they must represent an independent facet of some essential dimension of a system's performance.

This restriction is met for the present study by limiting the number of indices for which dollar benefits are claimed to a single one -- index 54. This index measures the time that certificated controllers were in conflict with aircraft of the IFR x VFR variety while working identical traffic samples with both the ARTS and manual systems. This time in conflict is then translated into the probability of a midair collision. The avoidance of such collisions is, undoubtedly, an important function of the controller's job.

In general, the method for determining whether a specific terminal location qualifies for an ARTS III installation will be to compare the costs of installing and maintaining this system with the benefits from the expected reduction in numbers of midair collisions at this location. A cost to benefit ratio which is less than, or equal to, unity, qualifies the terminal.

Summary of Method for Determining the C/B Ratios

The incremental costs needed to purchase ARTS III equipment at all 29 sites is estimated below to be $33.4 million. Suppose a midair collision to have a dollar (dis) benefit of $22.2 million. Then 33.4/22.2, or 1.5 midairs would have to be avoided for the entire useful

life of the equipment in order to warrant the purchase of ARTS III. The useful life of ARTS III is, probably, close to 20 years, but since all new improvements in technology are usually vulnerable to being made obsolete prematurely by newer improvements in technology, the more conservative estimate of ten years was used in the study. For the sake of arithmetic, assume that there are 30 installation sites, so that 1.5/30, or 0.05 midairs must, on the average, be avoided at each terminal location included in the third lot buy for the entire period of ten years in order to justify the purchase of ARTS III.

Other estimates for costs ($C) and (dis)benefits of midair collisions ($B) define a new ratio that establishes the reduction in midair collisions that are necessary to justify the purchase of ARTS at each terminal location. The analysis which follows will attempt to estimate this ratio by: 1) determining the ten year system costs that are envisioned for the ARTS and the manual programs; the difference in these system costs is the numerator of the ratio, 2) estimating the value or dollar benefit resulting from avoiding the occurrence of a midair collision. This benefit was estimated, at first, as a parameter value that depended upon the decision maker's subjective valuation of the expected number of fatalities per midair accident, and his estimate of the dollar worth of each human's life. The number of midair collisions expected at each terminal location was derived from the historical record of accidents occurring in our Nation's airspace. The reduced numbers of accidents expected at each location were based upon the results of the

simulated experiment; index 54. The summary graph, Figure 10 (p. 129) is presented as the resulting analytical tool for deciding between the ARTS and manual systems of air traffic control. Figure 10 indicates the value that must be placed on a midair collision in order to justify the purchase of ARTS III for a terminal having any given level of traffic activity. This is a convenient way to avoid having to make subjective judgments which are better left to others. The decision maker is required to set a dollar value on the cost of averting an accident that he thinks is justified.

However, a study dealing with realistic choices that matter cannot afford the luxury of avoiding key issues. The study must, at least, present a guideline for decision making. For this reason, an estimate of dollar costs per accident is presented in Table 24 for a variety of midair collisions involving several sizes of aircraft with differing numbers of occupants, earning various levels of income. The decision maker can then enter Figure 10 with any value, based upon his subjective estimate of the dollar benefits to be derived from averting an accident. A matrix of collision probabilities likely to occur in the next decade is shown in Table 23. Or, he can choose to enter Figure 10 with a conservative estimate -- the least costly end of the spectrum of values -- of the dollar benefits for averting a "typical" accident. This accident is represented by the weighted average of the matrix of collision possibilities shown in Table 23. By using the least costly estimate for an average accident, the decision maker would conclude, as the study does, that

the purchase of ARTS III equipment is justified at every terminal location included in the third lot buy.

## COST ESTIMATES

### Incremental Costs

Cost compilations were based on data supplied by the National Airspace System Program Office of the FAA for three example locations. 17/ This office is charged with the responsibility for implementing the ARTS III program.

A. Fixed Costs:

| | Burbank | Louisville | Birmingham |
|---|---|---|---|
| Basic ARTS III Contract Cost | $520,000 | $509,000 | $509,000 |
| Basic ARTS III In-House Cost | 66,000 | 66,000 | 66,000 |
| ATC Expansion Contract Cost | 36,400 | 38,800 | 54,400 |
| Fixed Cost per Location | $622,400 | $613,800 | $629,400 |
| | (X 10) | (X 10) | (X 10 locations) |
| Total Fixed Costs (30 locations) | | | $19.0 millions |

B. Annual Operating Costs:

| Annual Operating Costs: | ARTS III | Manual | Difference | |
|---|---|---|---|---|
| Birmingham | $137,120 | $ 86,480 | $ 50,640 | (X 10 locations) |
| Louisville | 199,200 | 119,200 | 80,000 | (X 10 locations) |
| Burbank | 125,280 | 35,920 | 89,360 | (X 10 locations) |
| | | | $2,200,000 | (30 locations) |

B. Total Operating Cost Increment: (10 years; 30 locations) = $22.0 millions

Total (A + B) $41.0 millions

17/ The three example locations were selected to represent the low, medium and high points of the spectrum of candidates. Each example, therefore, represents one-third of the total number of approximately 30 locations; or 10 locations.

C. Reduction in Training Costs Claimed

Savings in the operational costs of training new controllers are claimed for the reduction of ARTS III at 29 candidate terminals in the amount of $200,000 for each location over a period of 10 years; a total of $5.8 million. This estimate is based upon the work performed by The MITRE Corporation. 18/

— $ 5.8 million

Savings are claimed in the amount of the contract cancellation costs for not exercising the option to procure the third lot.

— $ 1.8 million

Total 10 year savings — $ 7.6 million

| | |
|---|---|
| Total Increment: (Total A+B-C) | $33.4 million |
| Average Increment per Terminal ($33.4 millions/30) | $111,300 |

18/ For the detailed calculations and assumptions see The MITRE Corporation report, Ref. 8.

ESTIMATES OF DOLLAR BENEFITS

A summary outline of the method used to calculate the benefits attributable to a specific ARTS III candidate location is shown below. The discussion which follows is keyed to this outline:

A. Estimate of Number of Midair Collisions Likely to Occur in FY 1977

The historical record of midair accidents is shown in Table 19 for the years 1938 through 1970. It is likely that these accidents will increase during the next decade due to 1) an increase in operations, 2) a larger cross-sectional collision area due to increased numbers of bigger sized aircraft, 3) increased speeds from the introduction of more numbers of jet aircraft. Only the first of these factors, increased operations, was included in the study's estimate of the number of accidents likely to occur in FY 1977.

An analysis was made of the relationship demonstrated between the number of accidents and traffic activity levels. Since a midair collision is a rare event it is difficult to discern an objective pattern capable of identifying potential hazards. For this reason, the data of actual midair collisions was supplemented by an analysis of the number of hazardous near misses in an independent study conducted by the FAA. 19/

Table 20 depicts the number of near miss incidents recorded at various major terminal locations for the year 1968. The traffic activity during 1968 for these terminals is shown in the right hand column. This activity includes VFR traffic at all tower equipped

19/ Near Midair Collision Report, 1968; see Ref. 9.

## Detailed Outline and Results of Cost/Benefit Analysis

| | Factor | Source | Estimate |
|---|---|---|---|
| A.1. | M = Number Midair Accidents, 1968 | Historical Record, shown in Table 19 | M = 38 |
| 2. | F = Increase forecasted for 1977 | "Aviation Forecasts, 1972-1983" | F = 1.64 |
| A. | Total Midair Accidents Forecasted, 1977 | | 62 |
| B.1. | $P_1$ = Proportion of Near Misses in Terminal Area | Near Miss Collision Report of 1968 | $P_1$ = .64 |
| 2. | $P_2$ = Proportion of IFR X VFR Near Misses | Near Miss Collision Report of 1968 | $P_2$ = .55 |
| 3. | $P_3$ = Proportion at an Individual Terminal $\frac{a}{b} = \frac{\text{Near Misses at Individual Terminal}}{\text{Total Terminal Near Misses Reported}}$ | a) Fig. 9<br>b) Near Miss Collision Report of 1968 | a) $P_3a$ = 17.825 X<br>X = Traffic Activity (in millions)<br>b) $P_3.b$ = 719<br>$P_3$ = .025 X |
| B. | Proportion of Midairs at an Individual Terminal: | $(P_1)(P_2)(P_3)$ | = .0088X<br>X = traffic activity, 1977 (in millions) |
| C. | R = Percent Reduction in Midair Accidents | Experimental Result | R = 0.4 |
| D. | S = $ Benefit for Avoiding (1) Accident | 1. See Fig. 10<br>2. Table 23 | 1. Parameter<br>2. $7,320,000 |
| E. | C = $ Annual Program Cost at Individual Terminal | Contract Price, plus Program Estimate | $C = \frac{\$(33.4)(10^6)}{(10)(30)}$<br>$C = 111,300 |

**Basis for Decision**; A x B x C x D = E; Equation 1

$$\begin{array}{ccccccc} (A) & \cdot & (B) & \cdot & (C) & \cdot & (D) = E \\ (62) & & (p.0088\ X) & & (.4) & & (S) = \$111,300 \end{array}$$

A graphical presentation of Equation (1) is shown in Figure 10.

Table 19

MIDAIR COLLISIONS - U.S. CIVIL AVIATION
1938 - 1970

| Year | Number Accidents Total | Number Accidents Fatal | Number Fatalities | Air Carrier Air Carrier | Air Carrier Gen. Aviation | Air Carrier Military | Gen. Aviation Military | Gen. Aviation Gen. Aviation |
|---|---|---|---|---|---|---|---|---|
| 1938 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 3 |
| 1939 | 6 | 6 | 12 | 0 | 0 | 0 | 1 | 5 |
| 1940 | 14 | 13 | 26 | 0 | 0 | 0 | 1 | 13 |
| 1941 | 13 | 5 | 7 | 0 | 0 | 0 | 0 | 13 |
| 1942 | 12 | 10 | 21 | 0 | 0 | 2 | 0 | 10 |
| 1943 | 31 | 14 | 14 | 0 | 0 | 0 | 2 | 29 |
| 1944 | 11 | 6 | 6 | 0 | 1 | 0 | 0 | 10 |
| 1945 | 20 | 6 | 9 | 0 | 1 | 1 | 0 | 18 |
| 1946 | 38 | 15 | 25 | 1 | 0 | 0 | 4 | 33 |
| 1947 | 49 | 30 | 54 | 0 | 1 | 0 | 5 | 43 |
| 1948 | 30 | 15 | 47 | 0 | 0 | 0 | 3 | 27 |
| 1949 | 17 | 11 | 89 | 0 | 3 | 1 | 2 | 11 |
| 1950 | 7 | 3 | 11 | 0 | 0 | 0 | 0 | 7 |
| 1951 | 13 | 7 | 17 | 1 | 2 | 0 | 3 | 7 |
| 1952 | 14 | 6 | 14 | 0 | 3 | 0 | 3 | 8 |
| 1953 | 9 | 0 | 0 | 1 | 0 | 0 | 2 | 6 |
| 1954 | 16 | 10 | 18 | 0 | 0 | 1 | 1 | 14 |
| 1955 | 21 | 8 | 24 | 0 | 3 | 0 | 2 | 16 |
| 1956 | 17 | 11 | 161 | 1 | 1 | 0 | 1 | 14 |
| 1957 | 15 | 6 | 19 | 0 | 0 | 1 | 4 | 10 |
| 1958 | 16 | 12 | 86 | 0 | 0 | 2 | 2 | 12 |
| 1959 | 13 | 10 | 20 | 0 | 0 | 0 | 3 | 10 |
| 1960 | 26 | 10 | 152 | 1 | 4 | 0 | 2 | 19 |
| 1961 | 20 | 10 | 22 | 0 | 0 | 0 | 0 | 20 |
| 1962 | 19 | 9 | 27 | 0 | 0 | 0 | 5 | 14 |
| 1963 | 13 | 3 | 6 | 0 | 0 | 0 | 2 | 11 |
| 1964 | 15 | 7 | 12 | 0 | 0 | 0 | 2 | 13 |
| 1965 | 27 | 14 | 30 | 1 | 0 | 0 | 1 | 25 |
| 1966 | 27 | 11 | 33 | 0 | 1 | 0 | 1 | 25 |
| 1967 | 26 | 20 | 157 | 0 | 2 | 1 | 3 | 20 |
| 1968 | 38 | 24 | 71 | 0 | 3 | 0 | 1 | 34 |
| 1969 | 31 | 12 | 120 | 0 | 4 | 0 | 3 | 24 |
| 1970 | 37 | 21 | 56 | 0 | 0 | 0 | 4 | 33 |

Prepared by FS-50
3/2/71

secondary airports within the range and jurisdiction of the primary airport's radar. The graphical presentation of these data in Figure 8 reveals that a near proportional, statistically significant, relationship exists between the number of near misses reported and the record of traffic activity. This relationship was used below to estimate the number of near miss incidents that are likely to occur at any given terminal, but for purposes of the discussion at hand this relationship was first used to estimate the total number of midair accidents that can be expected to occur in FY 1977. The number of midair accidents reported in 1968 was 38. The ratio of the number of total operations forecast for 1977 compared to 1968 is 1.64. Assuming that hazardous near misses provide a good proxy for actual accidents (the cliche, "where there's smoke there's fire" will have to suffice in place of a more elegant explanation which says the same thing), we have a logical basis for expecting that the number of midair accidents in 1977 will be $38 \times 1.64 = 62$.

The identical method, without the explanation, is used by the National Transportation Safety Board to forecast their estimate of the number of accidents likely to occur in the next decade.

> "Forecasts indicate a growth by a factor of 1.7 in the general aviation fleet and by a factor of 1.5 in the air carrier fleet over the next 10 years. In the same time period, the total number of operations of these fleets will be half again as large as they are today. Assuming the accident and fatality rates are the same for the next 10 years as they were for the last 10, we would expect the number of such accidents to increase by 50 percent; that is, 335 accidents and 792 fatalities for the 10 year period." 20/

20/ Report of Proceedings of the NTSB into the Midair Collision Problem, p. 1; see Ref. 10.

For this study, the number of operations forecasted for FY 1977 were obtained from official FAA estimates: 21/

| | FY 1968 | FY 1977 | Ratio |
|---|---|---|---|
| Total Itinerant Operations (millions) | 32.4 | 53.2 | 1.64 |

B. Proportion of Midair Accidents at an Individual Terminal

This section of the study attempts to determine how the number of midair accidents forecast for FY 1977 (a total of 62) will be distributed among those terminal locations identified in the third lot buy of ARTS III equipment. The probability that one of these locations will have an ARTS III preventable accident is represented by the product of three separate probabilities:

1) $P_1$ = The probability that the accident will occur in a terminal area.

2) $P_2$ = The probability that the accident will be of the "unknown" vs. "known" (IFR x VFR) variety.

3) $P_3$ = The probability that a given third lot buy location will be one of the terminals at which the accident will occur.

The calculations of these separate probabilities are shown below. They are based on the "Near Miss Collision Report of 1968." The data from this report used in this study are reproduced as Table 21.

The probability of a midair collision occurring in the terminal area was calculated as the ratio of the number of near misses reported

21/ "Aviation Forecasts, Fiscal Years 1972-1983," Office of Aviation Economics, FAA; September 1971.

Table 20

Record of Hazardous Near-Misses in Terminal Areas, 1968

| Location | Near-Miss Incidents | CY 1968 Traffic Activity ($10^4$) IFR; VFR |
|---|---|---|
| 1. Los Angeles | 74 | 87.8 |
| 2. New York | 53 | 151.1 |
| 3. San Francisco | 38 | 131.4 |
| 4. Washington | 24 | 45.6 |
| 5. Philadelphia | 15 | 52.5 |
| 6. San Diego | 19 | 76.7 |
| 7. Chicago | 21 | 109.0 |
| 8. Phoenix | 12 | 105.6 |
| 9. Kansas City | 11 | 44.7 |
| 10. Denver | 17 | 43.0 |
| 11. Columbus | 6 | 42.0 |
| 12. Dallas | 10 | 61.4 |
| 13. Seattle | 11 | 47.0 |
| 14. Detroit | 7 | 69.8 |
| 15. Oklahoma City | 9 | 37.9 |
| 16. Atlanta | 6 | 59.5 |
| 17. Indianapolis | 5 | 19.7 |
| 18. Minneapolis | 9 | 54.7 |
| 19. Norfolk | 6 | 41.4 |
| 20. Cleveland | 7 | 36.0 |
| 21. Miami | 10 | 124.5 |
| 22. Tampa | 7 | 46.7 |
| 23. Dayton | 6 | 31.9 |
| 24. Honolulu | 8 | 30.4 |
| 25. Houston | 7 | 41.4 |
| 26. Sacremento | 8 | 47.2 |
| 27. St. Louis | 8 | 39.2 |
| 28. Boston | 6 | 46.5 |
| 29. Buffalo | 6 | 20.7 |
| 30. Las Vegas | 7 | 35.5 |
| 31. Memphis | 6 | 21.2 |
| 32. Pittsburgh | 3 | 36.8 |
| 33. Portland, Ore. | 3 | 22.3 |
| 34. San Antonio | 4 | 67.9 |
| 35. Louisville | 3 | 26.7 |
| 36. New Orleans | 3 | 36.6 |
| 37. Cincinnati | 2 | 22.9 |
| 38. El Paso | 2 | 15.8 |
| 39. San Juan | 2 | 29.3 |
| 40. Nashville | 2 | 17.1 |
| TOTAL NEAR MISSES | 496 | Total Primary and Secondary Airports |

SOURCE: Near Midair Collision Report of 1968, FAA, July 1969.
Traffic Activity, Office of Aviation Economics, EC-200

in the terminal area (719; from Table 21) divided by the total number of hazardous incidents recorded (1,128 p. ix of summary to report).

$$P_1 = \frac{719}{1128} = 0.64$$

The probability that a collision will be between an IFR and a VFR aircraft was calculated as the ratio of the number of incidents of this type in the terminal area (395, as shown in Table 21) divided by the total number of terminal incidents.

$$P_2 = \frac{(217 + 54 + 124)}{719} = 0.55$$

The inclusion of this single category of collision, IFR x VFR, is necessary in order to make the inferences drawn from the real world conform to the experimental findings: Index 54 is a measure of the time in conflict for the specific interaction of IFR x VFR aircraft.

The probability that an accident will occur at an individual terminal included in the third lot buy was postulated to depend on the traffic activity at this terminal. Table 20 indicates the terminal locations and traffic activity for 496 incidents recorded out of the total of 719. A graphical presentation of the postulated relationship between the number of hazardous near misses reported and traffic activity is shown in Figure 8. (The data are keyed to Table 20). The New York and Atlanta facilities were excluded from the data used in determining the estimated relationship because these facilities had ARTS equipment in place during 1968. In the case of Atlanta, this equipment was fully operational in

Table 21

## TERMINAL HAZARDOUS INCIDENTS (LOCATION) (NETWORK ANALYSIS)

### TERMINAL

| | |
|---|---|
| 1st Quarter | 205 |
| 2nd Quarter | 172 |
| 3rd Quarter | 200 |
| 4th Quarter | 142 |
| Total | 719 |

**INVOLVEMENT**

| | 1°Q | 2°Q | 3°Q | 4°Q | |
|---|---|---|---|---|---|
| AC/AC | 2 | 3 | 3 | 1 | 9 |
| AC/GA | 68 | 61 | 86 | 56 | 271 |
| AC/MIL | 12 | 15 | 10 | 10 | 47 |
| GA/GA | 57 | 40 | 57 | 36 | 190 |
| GA/MIL | 55 | 46 | 37 | 36 | 174 |
| MIL/MIL | 11 | 7 | 7 | 3 | 28 |
| TURBO/TURBO | 14 | 10 | 13 | 5 | 42 |
| TURBO/PISTON | 109 | 103 | 104 | 89 | 405 |
| TURBO/HELO | 3 | 1 | 2 | 1 | 7 |
| PISTON/PISTON | 75 | 55 | 72 | 46 | 248 |
| PISTON/HELO | 4 | 3 | 9 | 1 | 17 |
| HELO/HELO | 0 | 0 | 0 | 0 | 0 |

### ALTITUDE

**GROUND UP BEYOND 5 MI.**

| | |
|---|---|
| 1st Quarter | 66 |
| 2nd Quarter | 81 |
| 3rd Quarter | 90 |
| 4th Quarter | 61 |
| | 298 |

**2,000 FT. AGL AND ABOVE WITHIN 5 MILES**

| | |
|---|---|
| 1st Quarter | 33 |
| 2nd Quarter | 15 |
| 3rd Quarter | 18 |
| 4th Quarter | 17 |
| | 83 |

**GROUND TO 2,000 FT. AGL WITHIN 5 MILES**

| | |
|---|---|
| 1st Quarter | 106 |
| 2nd Quarter | 76 |
| 3rd Quarter | 92 |
| 4th Quarter | 64 |
| | 338 |

### TYPE OF FLIGHT

| Altitude | Type | 1°Q | 2°Q | 3°Q | 4°Q | |
|---|---|---|---|---|---|---|
| GROUND UP BEYOND 5 MI. | IFR/IFR | 2 | 5 | 1 | 3 | 11 |
| GROUND UP BEYOND 5 MI. | IFR/VFR | 43 | 57 | 66 | 51 | 217 |
| GROUND UP BEYOND 5 MI. | VFR/VFR | 21 | 19 | 23 | 7 | 70 |
| 2,000 FT. AGL AND ABOVE WITHIN 5 MILES | IFR/IFR | 2 | 0 | 1 | 0 | 3 |
| 2,000 FT. AGL AND ABOVE WITHIN 5 MILES | IFR/VFR | 21 | 10 | 10 | 13 | 54 |
| 2,000 FT. AGL AND ABOVE WITHIN 5 MILES | VFR/VFR | 10 | 5 | 7 | 4 | 26 |
| GROUND TO 2,000 FT. AGL WITHIN 5 MILES | IFR/IFR | 2 | 1 | 1 | 1 | 6 |
| GROUND TO 2,000 FT. AGL WITHIN 5 MILES | IFR/VFR | 35 | 28 | 32 | 29 | 124 |
| GROUND TO 2,000 FT. AGL WITHIN 5 MILES | VFR/VFR | 69 | 47 | 59 | 33 | 208 |

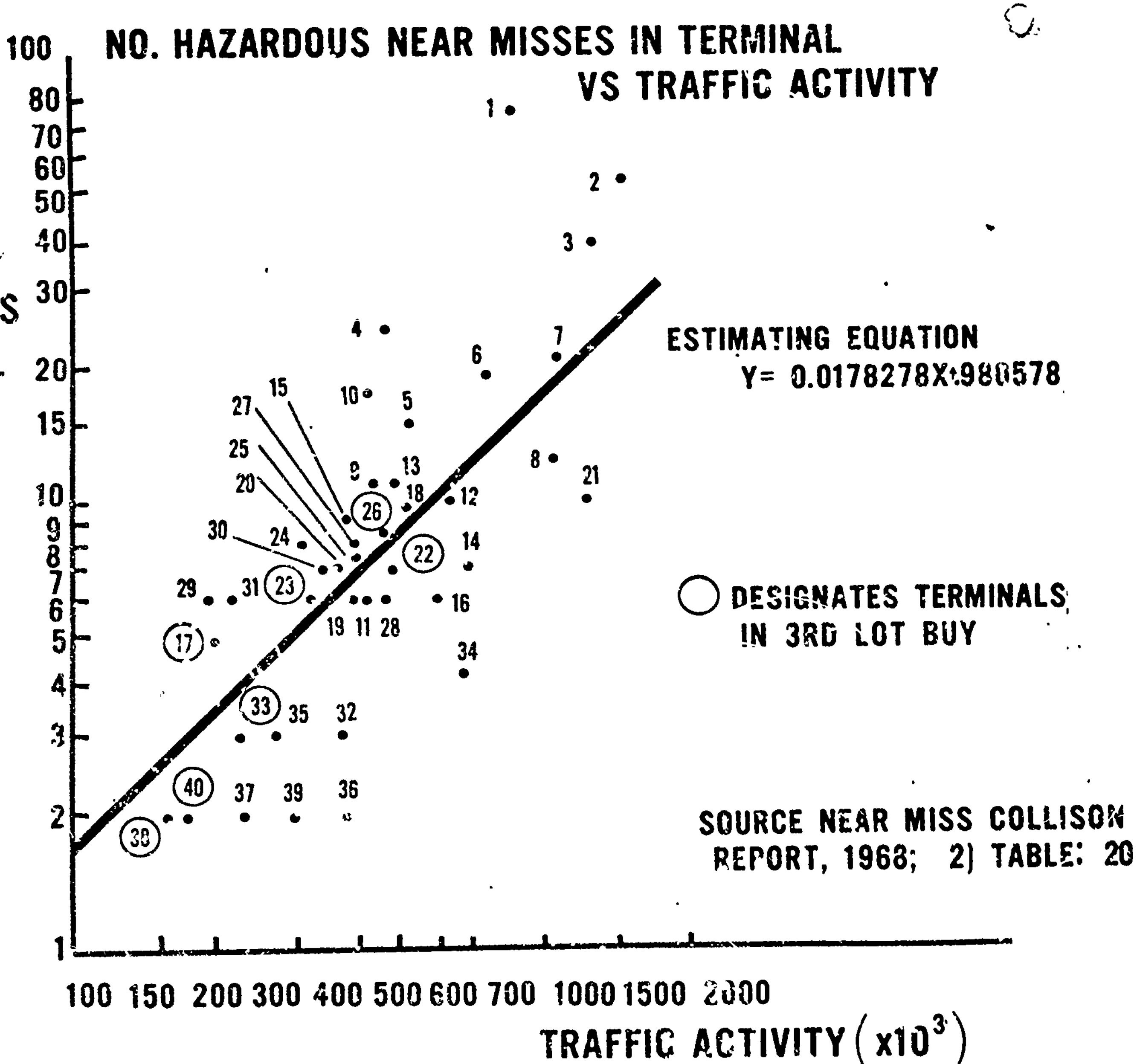
SOURCE: Reproduced from "Near Midair Collision Report of 1968," Appendix C-1, p. 119.

1968. The Los Angeles terminal was also excluded as a special case or "outlier." The number of near misses recorded for the Los Angeles terminal area was more than five standard deviations removed from the average value expected for a terminal with its level of activity. (In the case of Los Angeles the level of traffic activity appropriate to the estimation of near misses is, obviously, understated in Table 20.)

The number of near misses reported in the terminal area was found to be very nearly directly proportional to traffic activity as shown in Figure 8. The estimating equation shown is statistically significant and accounts for approximately 50 percent of the variance in the data for near misses in the terminal area. This represents an appreciable explaining capability when one realizes how varied are the reasons for a midair collision. Many factors influence and contribute to the generation of a single datum point for an accident or near miss, and yet, we can explain one half of the variation in these data with a single explanatory variable; traffic activity. Besides, this variable is the sole criterion being used for the installation of ARTS equipment. If, for example, weather conditions or other variables were included as significant explainers of near misses, then it would be imperative to include these other variables as part of the conditions required for a terminal to qualify for ARTS III. Since there is no stated intention to impose an array of installation criteria for ARTS III -- traffic activity is sufficient -- and, since there is no evidence that the incremental impact of increasing traffic levels on near miss incidents will be

FIGURE 8

NO. HAZARDOUS NEAR MISSES IN TERMINAL AREA, 1968



affected by the inclusion of other, unspecified, variables, it is appropriate to use the equation shown in Figure 8, as the basis for estimating the number of near misses at a terminal. 22/

Figure 9 was redrawn to include just those terminals included in the third lot buy. An adjustment was also made to make the relationship between near misses and traffic activity directly proportional. (The exponent of 0.98 was changed to 1.0. The better way to explain this change is to state that the data do not refute the hypothesis that the relationship is proportional). The number of near misses, Y, at a terminal location with traffic activity, X (in millions), is given by:

$$Y = 17.8275X \qquad (1)$$

The percent of variation in the data that is explained by the single variable, traffic activity, for these fewer numbers of terminals, is 65 percent (statistically significant). A comparison of the actual near misses recorded at ARTS III candidate locations with the numbers estimated by Equation (1) is shown in Table 22.

The probability that a near miss incident will occur at an individual terminal is given by:

$$P_3 = \frac{\text{Near Misses at Individual Terminal}}{\text{Near Misses at All Terminals}}$$

$$= \frac{17.8275X}{719} \quad (X = \text{traffic activity in millions})$$

$$= 0.25X \qquad (2)$$

22/ There is no need for this exegesis if we go along with the NTSB and "assume" that accidents will be proportional to traffic activity; see Footnote 20. The study preferred to conduct an independent analysis in order to confirm the relationship.

FIGURE 9

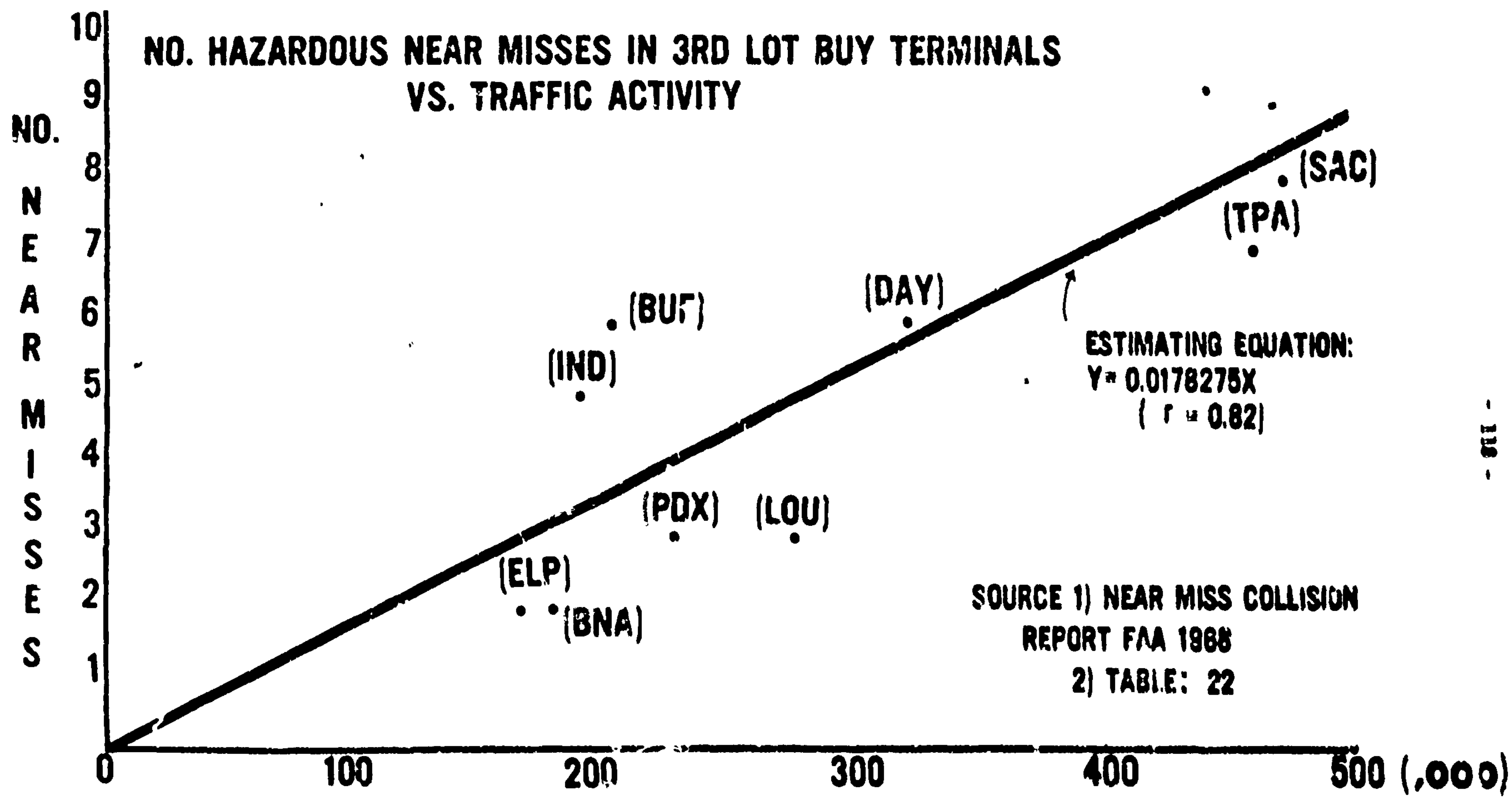

NO. HAZARDOUS NEAR MISSES IN 3RD LOT BUY TERMINALS
VS. TRAFFIC ACTIVITY
NO. NEAR MISSES
10
9
8
7
6
5
4
3
2
1
0
100
200
300
400
500 (,000)
(SAC)
(TPA)
(DAY)
(BUF)
(IND)
(PDX)
(LOU)
(ELP)
(BNA)
ESTIMATING EQUATION:
Y= 0.0178275X
( r = 0.82)
SOURCE 1) NEAR MISS COLLISION
REPORT FAA 1968
2) TABLE: 22

Table 22

ARTS III Terminals; Third Lot Buy

| Location | Near Misses | |
|---|---|---|
| | Actual Reported No. | Estimated by Equation[1/] |
| Indianapolis | 5 | 3.5 |
| Tampa | 7 | 8.3 |
| Dayton | 6 | 5.7 |
| Sacramento | 8 | 8.4 |
| Buffalo | 6 | 3.7 |
| Portland | 3 | 4.0 |
| Louisville | 3 | 4.8 |
| El Paso | 2 | 2.8 |
| Nashville | 2 | 3.0 |
| AVERAGE | 4.7 | 4.9 |

1/ Estimating equation:
$Y = 17.8275\,X$; X in units of $10^6$
($r = 0.82$)

SOURCE: ibid. Figure 8.

The proportion of midair collisions that are expected to occur at an individual terminal with traffic activity "X" in millions, is, therefore, given by:

$$(P_1)(P_2)(P_3) = .1038X \qquad (3)$$

C. Percent Reduction in Midair Accidents With ARTS III

Index 54 indicates that the time in conflict for a certificated controller is significantly less when he is using ARTS III. It is argued that the probability of midair collisions is proportional to the time that aircraft are in conflict. Thus,

$$P\left[(\text{collision})\right] = k\left[(\text{Index } 54)\right] \qquad (4)$$

The following arguments are offered in support of this contention:

1) It is clear that Equation (4) is in direct contradiction with the concept of "see and be seen." If this concept were an effective method for separating aircraft then the probability of a collision would be in an inverse relation to the time in conflict — the longer an aircraft is in conflict the better are its chances of seeing the conflict and resolving it. The first argument, then, in support of our contention is to examine the validity of the "see and be seen" concept.

The more obvious comment to make is that if this concept were valid there would be no need for any air traffic control system. The desire for governmental action to provide a better system of air traffic control -- and we have been at it since 1935 -- is a sufficient reason, therefore, for deciding that the concept of "see and be seen" is deficient.

Other studies confirm this deficiency. The "Near Midair Collision Report of 1968," for example, devotes a summary chapter to the dangers inherent in this (now) method of controlling aircraft. The following items are cited from this report:

a) "The largest number of NMAC incidents occur when both aircraft are operating VFR and "see and be seen" is the only means of providing separation."

b) "Distractions from normal visual scan caused by cockpit duties, mission requirements, or navigation requiring concentration, result in air traffic conflicts."

c) "Maneuvering in terminal areas between aircraft having a wide divergency of performance characteristics sets up hazardous situations because of the difficulty of assessing the rate of closure with any reasonable degree of accuracy."

The National Transportation Safety Board, 23/ Congressional Committees and the press have, likewise, expressed concern over the problem of midair collisions and the inadequacy of the concept of "see and be seen." A description of this concern is summarized in the following Associated Press Release —

23/ An "Historical Development of the 'See and Be Seen' Concept" is provided by the NTSB as Appendix 3 to their summary of the proceedings of the Midair Collision Problem; ibid. Ref. 10.

MIDAIR COLLISIONS

BY JAMES R. POLK

WASHINGTON (AP)-GOVERNMENT EFFORTS TO END DEADLY MIDAIR COLLISIONS HAVE BECOME CAUGHT IN A FIGHT BETWEEN TWO SAFETY AGENCIES OVER AN OLD FLYING RULE LEFT OVER FROM THE LINDBERGH DAYS--THE RULE OF "SEE AND BE SEEN."

IN A JET AGE WITH AIRLINERS FLYING 600 MILES AN HOUR, A SAFETY BOARD IS QUESTIONING WHETHER A PILOT'S EYE IS FAST ENOUGH TO RELY UPON TO SEE AND AVOID COLLISIONS.

THE LATEST DISASTER THAT KILLED 49 IN A CRASH BETWEEN AN AIR WEST JET AND A MARINE CORPS FIGHTER PLANE SUNDAY NEAR LOS ANGELES MET ALL THE CLASSIC CONDITIONS:

CLEAR, SUNNY SKIES. A CROWDED AIRLINER FLYING UNDER RADAR RULES, ONLY A FEW MINUTES AWAY FROM ITS AIRPORT. ANOTHER PLANE ZIPPING ALONG BY VISUAL RULES--WHAT THE RADAR PEOPLE CALL "UNKNOWN TRAFFIC." FAILURE TO SPOT IT SOON ENOUGH. DEATH.

THE TRAGEDY ADDED TO AN ALREADY GRIM LIST OF NUMBERS:

--MIDAIR COLLISIONS HAVE RESULTED IN NEARLY TWO-THIRDS OF ALL DEATHS, 249 OUT OF 395, IN U.S. JETLINER CRASHES OVER THE PAST FOUR YEARS.

--ALMOST ONCE A DAY, SOMEWHERE IN THE NATION, ANOTHER JETLINER HAS A CLOSE BRUSH WITH A PRIVATE PLANE IN WHAT THE GOVERNMENT LABELS A "NEAR-MISS." THE STUDY CONTAINING THESE STATISTICS CITED LOS ANGELES AS THE MOST DANGEROUS AREA, NEW YORK SECOND.

--IN THE NEXT 10 YEARS, ANOTHER GOVERNMENT STUDY PREDICTS, 526 PERSONS WILL DIE IN AIRLINE DISASTERS IN MIDAIR IF TODAY'S ODDS AREN'T REDUCED.

THE LOS ANGELES CRASH ENDED NEARLY TWO YEARS FOR THE NATION'S MAJOR AIRLINES WITHOUT A FATALITY ON A REGULAR JET FLIGHT, A SAFETY STRETCH WITHOUT PRECEDENT IN MODERN AVIATION HISTORY.

PD12:07PED 6/7

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2) An argument that more directly supports the contention that the probability of a midair collision is proportional to the time in conflict is provided by the "Report of the Department of Transportation Air Traffic Control Advisory Committee, 1969." 24/ This committee estimated the probability of a midair collision to be dependent upon the cross-sectional area of impact between two aircraft. In effect, the committee regarded a collision as a random event. This same assumption was adopted by a previous staff study of ARTS III. 25/ The analysis of cross-sectional areas of impact is an attempt to determine a precise value for the constant of proportionality (k) in Equation (4), but for the purposes of this study, the specification of the general form of the equation is sufficient. The argument that collisions are random events whose probability of occurrence depends on the geometry of intersecting bodies, supports the use of the proportional relationship shown in Equation (4).

3) The final argument in support of the contention that the probability of a midair collision is proportional to the time in conflict is provided by the following reasoning:

The contention is certainly true for a conflicting airspace that is the intersection of rectangular parallelpiped volumes that barely contain two aircraft. The longer an aircraft is in such tight quarters, the

24/ See Ref. 11; Vol. I, p. 47. Appendix C.3, which describes the work of Graham and Orr is also of interest in that it argues the more general proposition that the probability of a midair collision is proportional to the time spent in the terminal area.

25/ See Ref. 12.

(proportionally) greater is the likelihood of a collision. Now suppose that the confines of the parallelpipe were extended just a little to account for: 1) pilot reaction time, 2) controller reaction time, 3) wind conditions, 4) accuracy of the instruments controlling traffic; radars, altimeters, etc., and 5) all other system errors and variations in data. If we extended the dimensions of the airspace to provide for precisely that amount which accommodates all of the expected sources of error, we would define a conflicting airspace as that airspace in which the probability of a midair collision was proportional to the time in conflict. As a matter of fact, such a definition would be a most rational method for determining the legal standards for separating aircraft. In other words, if legal separation standards were established in this manner, Equation (4) would be true, by definition. However, it is not necessary to offer the record of the hearings in which these standards were established in order to support the study's contention. There need not have been a conscious effort to define airspace separation standards according to the above description. If there is a strong belief that a rational method of allowing for successive increments of airspace to accommodate each independent source of error in the system of air traffic control was, indeed, used in defining these standards, then the same degree of belief supports the contention that Equation (4) is a valid

representation of the relationship between midair collisions and time in conflict. 26/

The graphical representation of Index 54, included in a previous section of the report, is repeated below; Figure 5A. The data points which are shown represent observations for the first half hour (f), the second half hour (s) and the combined hour (C) of the experiment. In effect, the value shown for the full hour has twice the weight as the half hour values, and is the principal finding of the study: the average time in conflict for all teams and all sample types employed in the experiment was 149 seconds per each simulation hour for the manual system; 90 seconds for the ARTS system. Equation (4) -- midair accidents are proportional to time in conflict -- and Equation (1) -- midair accidents as measured by the number of near misses are proportional to the level of traffic activity -- imply Equation (5). The time in conflict is proportional to the level of traffic activity.

$$T = cX \qquad (5)$$

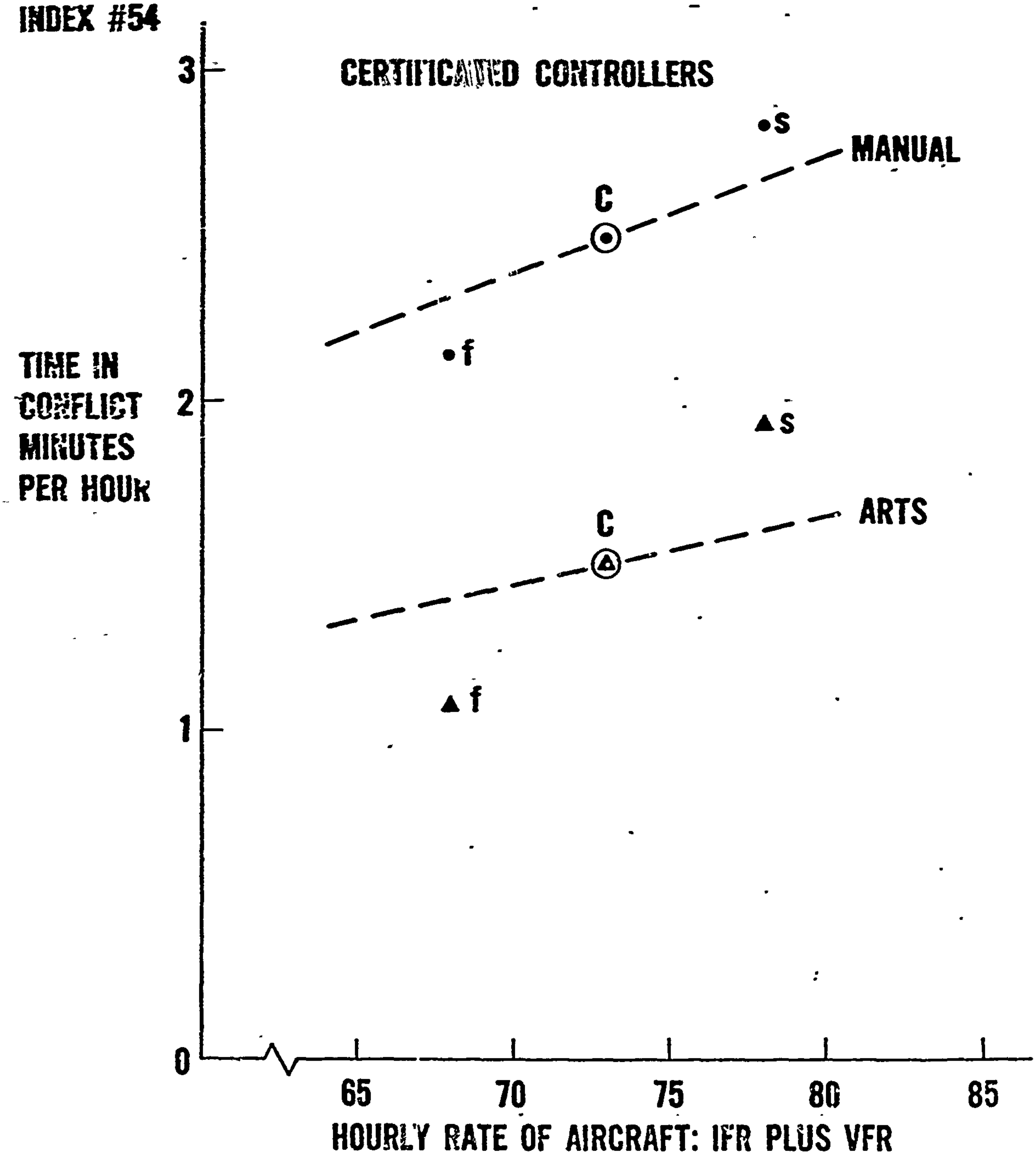
Figure 5A is a graphical presentation of this equation. The proportional lines were drawn through the origin (when there is no traffic, there is no time in conflict) and a point which represents the combined

26/ This argument was suggested by A. H. Schainblatt of the University of California at Santa Barbara who, in the role of a general consultant, was kind enough to read the earlier drafted versions of this study. A description of an attempt to devise separation standards by using rational methods consistent with his argument is provided by the work of Holt and Marner; see Ref. 11.

FIGURE 5 A

# TIME IN CONFLICT-IFR/VFR-MINUTES PER SIMULATION HOUR VS IFR + VFR HOURLY RATES OF TRAFFIC

INDEX #54



hour value for index 54. The slope of the line for the time (in seconds) spent in conflict is, therefore: 149 for manual; 90 for ARTS. This results in a constant ratio of 90/149 = 0.6 to reflect the reduced time spent in conflict for ARTS at all activity levels. From Equation (4) we expect that the number of midair collisions will have the same ratio. The percent reduction in midair collisions resulting from the use of ARTS is, therefore, estimated as:

$$R = (1.0 - 0.6) = 0.4, \text{ or } 40 \text{ percent} \tag{6}$$

D. $ Benefit for Avoiding an Accident

1) In this section of the study we permit this dollar benefit to be a parameter; to assume whatever value is required to justify the installation of ARTS III equipment at alternative levels of traffic activity.

This value is obtained by solving the equation:

$$\begin{array}{ccccccccc} (A) & \cdot & (B) & \cdot & (C) & \cdot & (D) & = & (E) \\ 62 & & 0.0088X & & 0.4 & & \$B & & \$111{,}300 \end{array} \tag{7}$$

The value for E = $111,300 was determined in the preceding section as the increment in annual costs required to install and operate an ARTS III system for 10 years at a typical third lot location. An appropriate point in time for comparing the added costs required to achieve given benefits is halfway through the decade of intended use; i.e., FY 1977.

Figure 10 is a graphical presentation of Equation (7). It indicates that at the activity level forecast for the Syracuse terminal area in

1977, the dollar benefits from avoiding a midair collision must be in excess of $3.77 million. All other ARTS III terminal areas have traffic levels which are forecasted to be higher than Syracuse and would, therefore, require lower dollar benefits, as shown in Figure 10.

In order to complete our analyses of costs and benefits to determine whether an ARTS III installation is justified at a given terminal location, it remains for us to estimate the expected value of avoiding a midair collision. On the basis of our analysis, we will use the decision rule that an installation of ARTS III is justified at Syracuse, and, therefore, at all other locations in the third lot buy, if this value exceeds $3.77 million.

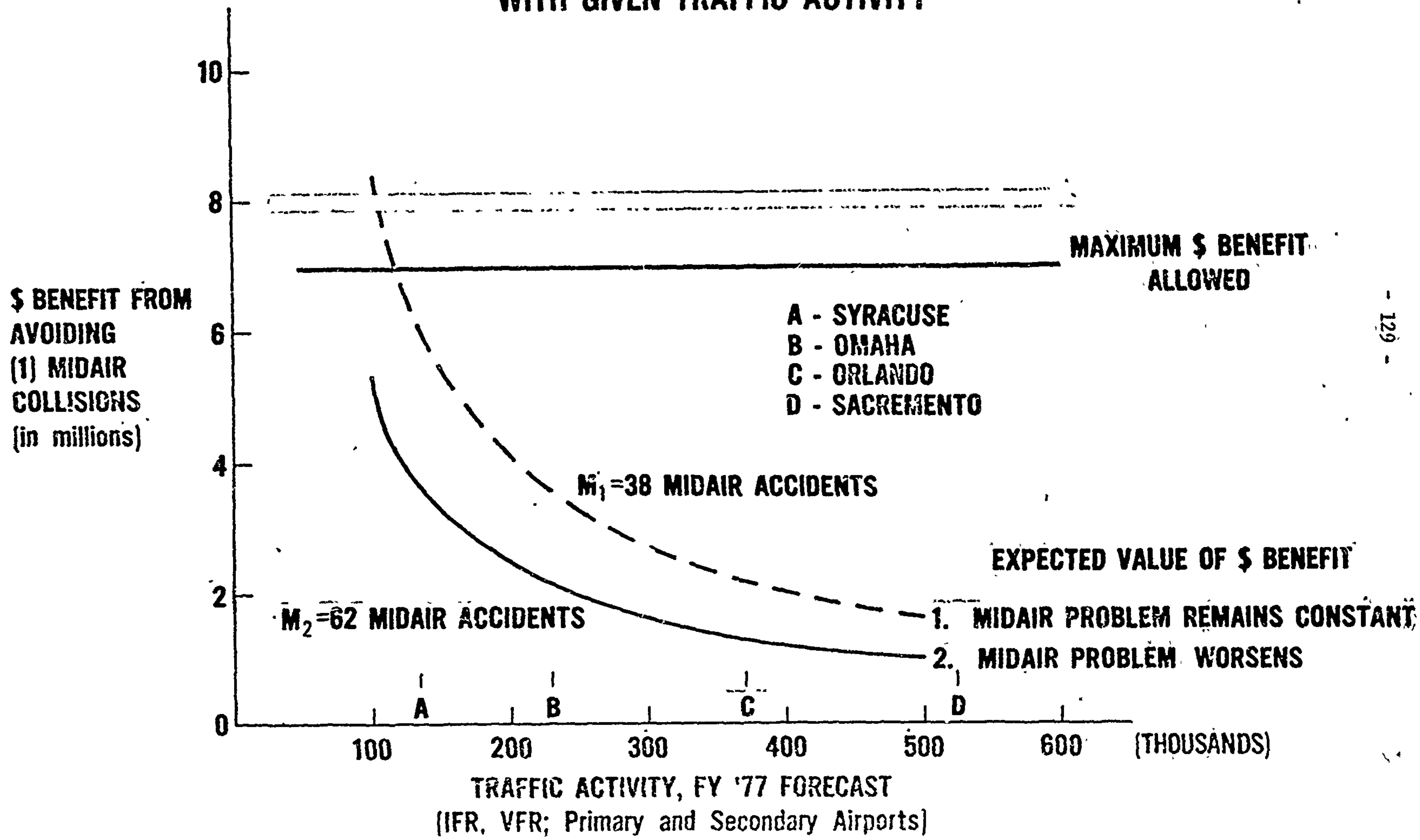
2) Determination of the Value of Preventing a Midair Collision

We have attempted previously to advise the reader of the subjective judgments that are required in even the most quantifiable and objective portions of this study. It is now necessary to advise him that this next section of analysis, the dollar value to be attributed to averting a midair collision is inherently more subjective. And it should be. The decision maker cannot avoid facing this decision head-on although quantitative analyses can identify the subjective elements for him, narrow their range, and indicate the sensitivity of the decision to these elements. But, there are limits to the uses to which numbers can be put, and these must be understood as well. For example, it may be a delusion to attempt to estimate the value of an average accident when these values are not linear, but are a series of discrete constraints defined by the whimsical moods of society (if it were only possible to define society). This means that while it is possible to estimate the costs of this accident or any number that society will tolerate, these estimates have meaning only if the "breaking point" has not been reached.

Perhaps, the public will tolerate one more midair collision between airliners, that is, if a jumbo jet is not involved. But, it is likely that two midair collisions would result in a public outcry to revamp the Nation's air traffic control system. Does it make sense, then, to

FIGURE 10

DOLLAR BENEFITS FROM AVOIDING MIDAIR COLLISION REQUIRED TO JUSTIFY ARTS III INSTALLATION AT TERMINALS WITH GIVEN TRAFFIC ACTIVITY



estimate that one accident will cost, say, $10 million and that two will, therefore, cost $20 million? It does, only if the world of accidents remains linear and if the "breaking point" has not been reached. However, consideration of where systems break down may, indeed, be more appropriate to decision making, even though it is often impossible to define this breaking point numerically. Pleas by governmental agencies to the effect, for example, that our "American way of life is threatened" or "the education of children will be compromised" unless the public makes a given investment may be realistic and highly relevant comments, even if they are devoid of numerical content. The practical effect of invoking unquantified statements concerning where systems break down is that they may provide no guidelines whatever. All governmental agencies could plead that a single unsafe incident in their jurisdiction was one too many and the decision maker would have no rational method for allocating the Nation's resources among many unquantified pleas. However, it is clear that the assumption of a continuing linear relationship for the costs of accidents that one is required to make in order to provide numerical substantiation for the benefits claimed for ARTS III understates the advantages to be derived from this equipment.

For example, suppose that there were, say, a 97 percent probability that as many as "Q" midair accidents would not occur if the present manual system of control were in use. (Q is the level at which society withdraws its acceptance of the Nation's air traffic control system.) A central argument of this study is that the use of ARTS equipment is likely to increase this probability; say, to 98 percent. This is an essential piece of information that should be made known to the decision maker, but an analytical method which assumes that accidents may be aggregated linearly without regard for the limiting Q value is not able to provide this critical information.

Since the analytical method we intend to use in the following section understates the advantages of ARTS III---it is more difficult to justify an investment decision in a linear world in which the costs of accidents can be aggregated continuously---this study will assume that such a world exists, and that neither the ARTS nor manual systems of control will result in numbers of midair collisions that exceed society's level of acceptance.

There are three principal populations of aircraft -- air carrier; general aviation; military -- in two flight-rule categories -- IFR; VFR -- yielding a total of nine possible varieties of collisions involving all aircraft populations flying both sets of rules. The matrix of possibilities is shown in Table 23.

The probabilities of each type of collision are shown in Table 23 as the product of the relative proportion of aircraft in each of the three categories of aircraft types and the two kinds of flight rules that were forecast to be controlled by the Birmingham, Alabama, terminal in 1977. Birmingham was selected as a representative facility in the third lot procurement.

Table 24 is a compilation of the data used to value an accident in each of the population categories. Low and high estimates are shown. The average value of a typical midair collision (at a representative terminal like Birmingham) was estimated to be the weighted average of the probabilities and dollar values for the nine possible types of collisions.

A low estimate of $7.32 million and a high of $120 million result from this compilation.

The low estimate of $7.32 million for the average midair collision expected in 1977 in a terminal area such as Birmingham, is more than sufficient to justify the installation of ARTS III at all third lot locations. The margin of acceptance at Syracuse, the low end of the activity scale, is about two to one; $7.32 million benefits allowed; $3.77 millions expected.

Table 23

COMPUTATION OF THE PROPORTIONS
BY WHICH TO REPRESENT AIR CARRIER
GENERAL AVIATION AND MILITARY TRAFFIC
IN ONE COMPOSITE MIDAIR COLLISION

| Proportion of IFR Traffic $\pi_i$ | Proportion of VFR Traffic $\pi_j$ (1) AC = .013 | (2) GA = .867 | (3) Mil = .120 Sum = 1.00 |
|---|---|---|---|
| (I) AC = .527 | .0069 (Ix1) | .4569 (Ix2) | .0632 (Ix3) |
| (II) GA = .334 | .0043 (IIx1) | .2896 (IIx2) | .0401 (IIx3) |
| (III) Mil = .139 | .0018 (IIIx1) | .1205 (IIIx2) | .0167 (IIIx3) |
| Sum = 1.00 | | | |

Notes: IFR and VFR proportions were computed from traffic at Birmingham (to represent the airports in the third lot procurement) as forecast for FY 1977.

The computed ratios in this table were multiplied by the low and high (separately) dollar values shown in Table 19 to obtain the following estimates of the cost of a midair collision:

Low estimate = \$7,320,000
High estimate = \$120,000,000

The formula for the computation is:

$$\sum_{i=1}^{3} \sum_{j=1}^{3} \pi ij \ (V_i + V_j)$$

| | | | |
|---|---|---|---|
| Example: | .0069 (12 + 12) | = | .1656 |
| | .0043 (12 + 0.22) | = | .0525 |
| | .0018 (12 + 1.45) | = | .0242 |
| | .4569 (12 + 0.22) | = | 5.5833 |
| | .2396 (0.22 + 0.22) | = | .1274 |
| | .1205 (1.45 + 0.22) | = | .2012 |
| | .0632 (12 + 1.45) | = | .8500 |
| | .0401 (1.45 + 0.22) | = | .0670 |
| | .0167 (1.45 + 1.45) | = | .0484 |
| Weighted Average = | | | \$7.12 million |
| Government investigation cost | | | .20 |

Low Average Value of Typical Midair = \$7.32 million

Table 24

DATA USED TO ESTIMATE THE DOLLAR LOSS OF A MIDAIR COLLISION

| | | Low Estimate | High Estimate |
|---|---|---|---|
| **Air Carrier** | | | |
| Load factor | | 30% | 100% |
| Capacity | | 100 seats | 350 seats |
| Value of aircraft | | $6,000,000 | $30,0[illegible],000 |
| Value of a life | | $200,000 | $300,000 |
| Total loss | $V_1$ | $12,000,000 | $135,000,000 |
| **Military Aircraft** | | | |
| Value of aircraft | | $1,000,000 | $30,000,000 |
| No. of occupants | | 1 | 350 |
| Value of a life | | $200,000 | $300,000 |
| Invested training | | $250,000 | $750,000 |
| Total loss | $V_2$ | $1,450,000 | $135,750,000 |
| **General Aviation** | | | |
| Value of aircraft | | $20,000 | $3,000,000 |
| No. of occupants | | 1 | 10 |
| Value of a life | | $200,000 | $300,000 |
| Total loss | $V_3$ | $220,000 | $6,000,000 |

$200,000 to be added in each category for the cost of investigation.

Sensitivity Analysis

Since the entire section devoted to the determination of the dollar benefits attributable to an ARTS III installation consists of a series of multiplicative factors, the sensitivity of the above conclusion to the various elements of independent analyses can be quantified readily. With the determination of an approximate margin of two to qualify the installation of ARTS III at Syracuse, it means that any combination of changes, whose multiplicative effect is greater than 0.5, will not alter the conclusion: e.g., 1) traffic activity, 2) dollar benefits, 3) index 54, and 4) the forecast of midair collisions may all be reduced by 10 percent, with no effect on the conclusion to buy ARTS III ($0.9^4 = 0.52$).

Or, it is possible to deny the proposition promulgated by the NTSB and confirmed by this study that the midair collision problem will grow during the next decade as operations grow if significant and new methods of air traffic control are not adopted. In this case, there would be a 64 percent reduction in the dollar benefits claimed. Figure 10 shows both cases: 1) midair collisions are assumed to remain at the level of 38 experienced in 1968; 2) collisions are forecast to grow as operations grow to a level of 62 by 1977. The conclusion that the installation of ARTS III equipment is warranted at all third lot buy locations remains unchanged. Other combinations of changes in the data can be estimated in a similar manner.

# Appendix A

## Follow-On Analytical Investigations

Several "post-mortem" investigations were conducted:

A. NAFEC Operational Analysis and Debriefing.

I. NAFEC supervisory personnel evaluated the written record of conflict data in order to confirm their impressions, obtained through personal observation, of the relative safety of the two systems. An arbitrary weighting scheme was assigned to reflect the seriousness of all recorded violations. The results are presented below.

II. The controllers who took part in the experiment were provided with a multiple choice type of questionnaire designed to obtain their subjective opinion concerning the relative merits of the ARTS and manual systems of control. The responses dealing with a comparison of the two systems in regard to safety, expeditious movement of traffic and controller workloads were found to greatly favor ARTS. Little emphasis has been placed on these results, however. They were compiled as part of a standard debriefing procedure. 1/ Besides, it was clearly understood before the conduct of the experiment that expressions of controller satisfaction were not sufficient to justify the installation of ARTS III equipment. Experience with this equipment at the Atlanta and New York facilities indicated that the controllers liked the ARTS system just fine.

1/ The complete tabulation of responses to all questions asked is available from NAFEC as "Controller Questionnaire," Project 154-007-01X.

III. The Mitre Corporation performed statistical analyses of various specified mathematical relationships in order to determine those individual features of ARTS III that contributed most to the reduced numbers of conflicts observed with this system in use. These analyses are summarized below.

IV. The Transportation Systems Center performed a series of statistical investigations using these same mathematical relationships but with a view towards determining whether aircraft identified with an ARTS III data tag were better able to stay out of conflicts. This is in contrast to the previous analysis which was concerned only with each system's ability to avoid conflicts for all aircraft. Mode C, for example, on some given aircraft may make a controller's job easier so that other aircraft, without this equipment, benefit to the extent of avoiding conflicts. These analyses are, likewise, summarized below.

1. <u>NAFEC Operational Evaluation</u>

Two methods for measuring separation distances were employed: Method A used minimum slant range as the measure of separation. Method B used separation criteria in both vertical and horizontal directions. Four locational categories, I-IV, were considered. The weighting scheme employed for both category of violation and minimum separation distance is shown in Table A-1.

Applying these weights to the record of conflicts results in the summary tabulation shown in Table A-2. This tabulation confirms the conclusions provided by the more objective statistical analyses of variance. Conflicts were judged to be reduced in both vertical and horizontal directions for the certificated and trainee controller using ARTS. The trainee controller benefitted to a greater extent.

Table A-1

WEIGHTS APPLIED TO REFLECT SEVERITY
OF CONFLICT, OPERATIONAL EVALUATION BY NAFEC

Locational Categories

I. On Localizer (End of runway - Outer marker)
II. On Localizer (Outside of outer marker)
III. Vector Area (Arrival Dump Zone)
IV. Other Area

Increments of Separation for Weighting Scheme

| Horizontal | Vertical |
|---|---|
| a) 0 to 0.99 miles | a) 0 to 299 feet |
| b) 1.0 to 1.99 miles | b) 300 to 599 feet |
| c) 2.0 to 2.99 miles | c) 600 to 850 feet |

Weights

Locational Category I-II

| Vertical \ Horizontal | a | b | c |
|---|---|---|---|
| a | 5 | 4 | 3 |
| b | 4 | 3 | 2 |
| c | 3 | 2 | 1 |

Locational Category III-IV

| Vertical \ Horizontal | a | b | c |
|---|---|---|---|
| a | 6 | 5 | 4 |
| b | 5 | 4 | 3 |
| c | 4 | 3 | 2 |

SOURCE: "Weighted Scores on Conflict Data"
Letter D. Brown (NA-516) to S. Horowitz (EC-100)

Table A-2

WEIGHTED SCORES OF CONFLICTS
OPERATIONAL EVALUATION BY NAFEC

| | ARTS | Manual |
|---|---|---|
| **NAFEC Controllers** | | |
| Horizontal Separation | 1.555 | 2.922 |
| Vertical Separation | 2.900 | 3.211 |
| **Field Controllers** | | |
| Horizontal Separation | 1.555 | 3.550 |
| Vertical Separation | 1.722 | 3.783 |

SOURCE: Ibid., Table A-1.

2. MITRE Statistical Analysis of Conflicts Data

The following descriptions and tabular presentations of these data have been reproduced from the MITRE report.

"4.3 Regression Methodology

As an informal part of the project, MITRE agreed to run some multiple regressions in the area of safety and index of orderliness. Three versions of index of orderliness were supplied by NAFEC, and the assumption is made, for the purposes of these regressions, that index of orderliness is a valid measure of conflicts, or potential midair collisions.*

Three regressions were performed,*

regression #1

$$I.O. + 1 = \alpha \ IFR^{\beta} \ VFR^{\gamma} \ Mode^{\delta}$$

regression #2

$$I.O. = 1 = \alpha \ IFR^{\beta} \ Mode^{\delta}$$

regression #3

$$I.O. + 1 = \alpha \ UNK^{\beta}$$

where

$\alpha$, $\beta$, $\gamma$, $\delta$ are the regression parameters to be determined (different for each regression run)

I.O. = index of orderliness
IFR = IFR radar count
VFR = VFR radar count
Mode = fraction Mode C equipped aircraft
UNK = radar count of all unknown aircraft where unknown is defined as follows:
Manual - all VFR
ARTS III - all non-mode C VFR

Data for the regressions was available for each minute of each run. The regression was run separately for manual and ARTS, certificated and non-certificated; thus there were 18 x 60 - 1080 data points per regression.

All three regressions are in exponent form. They may be converted to a linear form by taking logarithms of both sides, as follows:

$$\log (\text{I.O.} \div 1) = \log \alpha \div \beta \log \text{IFR} \div \gamma \log \text{VFR} \div \delta \log \text{MODE}$$

$$\log (\text{I.O.} \div 1) = \log \alpha \div \beta \log \text{IFR} \div \delta \log \text{MODE}$$

$$\log (\text{I.O.} \div 1) = \log \bar{\alpha} \div \beta \log \text{UNK}$$

The logarithm operation demands that no original variable take on a zero value. It is for this reason that the regressions are with I.0 ÷ 1 as the dependent variable, since I.O. can assume a zero value. In cases where the independent variables assumed zero values, a small positive value was substituted. Standard programs were IBM's Scientific Subroutine Package (SSP) for System 360 were employed to effect the regressions. The output is summarized in Appendix E."

-- SOURCE: "Results of MITRE's ARTS III Validation Effort," Ibid Ref. 8.

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*The form of the regression equations were specified in advance. The first of these versions recorded all potential conflicts without regard for whether violations were in the horizontal or vertical direction. The second version recorded violations in both directions, but included severe violations only. The third version was similar to the second, but the separation standards were somewhat relaxed.

3. Interpretation of MITRE's Regression Statistics

Comments will be confined to the index of orderliness version numbers 2 and 3 for certificated controllers. Version number 1 reflects slant range separation only for which no legal standard exists. And in keeping with our previous discussions, the interpretation of trainee performance will be limited solely to inferences about the ability to train controllers.

Regression number 1 tells us we can infer that the number of conflicts grow at a rate which is less than the square of the traffic (the rate to expect if a "gas molecule" collision model were appropriate). The exponent for IFR traffic ranges from 0.6 to 1.0. These values are statistically significant; they exceed their standard deviation by more than a factor of two.

However, the exponent to the level of VFR traffic does not differ statistically from zero. This result was not unexpected since the experimental design employed in the NAFEC simulation did not have sufficient variation in VFR traffic to estimate a reliable coefficient for this variable. VFR traffic was approximately constant in the experiment, and the statistical analysis confirms this.

The exponent to the proportion of Mode C behaves according to expectation in that it is a negative value; the higher the proportion of Mode C, the fewer the conflicts. But, there is a minor anomaly in that one would expect this relation to hold only for the ARTS III

Regression #1

$$I.0 + 1 = \alpha \; IFR^{\beta} \; VFR^{\gamma} \; Mode^{\delta}$$

| | | $\alpha$ | $\beta$ | | $\gamma$ | | $\delta$ | | Correlation Coefficients | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Version | Runs | r.c. | r.c. | s.d. | r.c. | s.d. | r.c. | s.d. | IFR | VFR | Mode | Multiple |
| 1 | MAN - CER | .304 | .574 | .070 | -.016 | .021 | -.413 | .202 | .28 | .15 | -.02 | .29 |
| | ARTS- CER | .316 | .508 | .062 | -.011 | .019 | -.732 | .187 | .28 | .15 | -.08 | .30 |
| | MAN -NCER | .342 | .557 | .079 | -.026 | .023 | -.399 | .217 | .23 | .12 | -.03 | .24 |
| | ARTS-NCER | .268 | .624 | .067 | -.050 | .020 | -.601 | .195 | .28 | .11 | -.06 | .30 |
| 2 | MAN - CER | .144 | 1.022 | .104 | -.043 | .031 | -.801 | .301 | .32 | .16 | -.04 | .33 |
| | ARTS- CER | .156 | .916 | .096 | -.012 | .029 | -1.301 | .290 | .32 | .18 | -.09 | .34 |
| | MAN -NCER | .218 | .889 | .112 | -.039 | .033 | -.814 | .305 | .26 | .13 | -.05 | .28 |
| | ARTS-NCER | .130 | 1.131 | .100 | -.128 | .030 | -.727 | .290 | .31 | .09 | -.05 | .34 |
| 3 | MAN - CER | .233 | .782 | .084 | -.043 | .025 | -.317 | .241 | .30 | .14 | -.001 | .31 |
| | ARTS- CER | .308 | .626 | .076 | -.013 | .023 | -.748 | .228 | .28 | .16 | -.06 | .30 |
| | MAN -NCER | .403 | .591 | .094 | -.023 | .028 | -.453 | .256 | .22 | .11 | -.02 | .22 |
| | ARTS-NCER | .251 | .763 | .079 | -.072 | .024 | -.566 | .230 | .28 | .10 | -.05 | .30 |

system. Logically, Mode C is a silent contributor to the manual system. It should have no effect on conflicts. Version 3 behaves nicely in that the exponent for this variable does not differ from zero for the manual system, whereas it is a negative value for ARTS. Version 2, however, shows a negative value for both systems. This is due, probably, to the fact that the equation forms used in regression 1 could not differentiate between specific transponder features: an aircraft with a Mode C transponder was still able to provide a double slash symbology when the manual system was being used. Therefore, the greater the proportion of Mode C equipped aircraft, the fewer the conflicts; even for the manual system. However, in all versions for the index of orderliness, the negative value is larger for the ARTS system, as it should be.

Regression number 2, deletes VFR traffic as an explanatory variable, since it was expected that its effect would not be significant. There is little change in the results. The exponent to IFR is about at the same level; a range from 0.6 to 0.9. Both sets of equations show a lower growth rate in conflicts using ARTS. The exponent to the proportion of Mode C transponders shows the same pattern described previously in regression number 1.

Regression 3, attempted to pinpoint the contribution made by Mode C; to differentiate between double slash identity available from the manual system and the actual reporting of altitude information. It should be noted that the growth rate for conflicts as the number of "unknown" aircraft grows is less for ARTS than manual. Moreover, the

Regression #2

$$I.0 + 1 = \alpha \; IFR^{\beta} \; Mode^{\delta}$$

| Version | Runs | $\alpha$ r.c. | $\beta$ r.c. | s.d. | $\delta$ r.c. | s.d. | Correlation Coefficient IFR | Mode | Multiple |
|---|---|---|---|---|---|---|---|---|---|
| 1 | MAN - CER | .327 | .540 | .055 | -.428 | .201 | .28 | -.02 | .29 |
| | ARTS- CER | .332 | .486 | .049 | -.741 | .187 | .28 | -.08 | .30 |
| | MAN -NCER | .385 | .502 | .062 | -.430 | .215 | .23 | -.03 | .24 |
| | ARTS-NCER | .332 | .520 | .053 | -.668 | .193 | .28 | -.06 | .29 |
| 2 | MAN - CER | .174 | .933 | .082 | -.838 | .300 | .32 | -.04 | .33 |
| | ARTS- CER | .165 | .892 | .076 | -1.311 | .289 | .32 | -.09 | .35 |
| | MAN -NCER | .259 | .808 | .087 | -.860 | .302 | .26 | -.05 | .28 |
| | ARTS-NCER | .227 | .866 | .079 | -.898 | .290 | .31 | -.05 | .32 |
| 3 | MAN - CER | .282 | .694 | .066 | -.354 | .241 | .30 | -.001 | .30 |
| | ARTS- CER | .325 | .600 | .060 | -.758 | .227 | .28 | -.06 | .30 |
| | MAN -NCER | .447 | .542 | .073 | -.480 | .254 | .22 | -.03 | .22 |
| | ARTS-NCER | .343 | .614 | .062 | -.662 | .229 | .28 | -.05 | .29 |

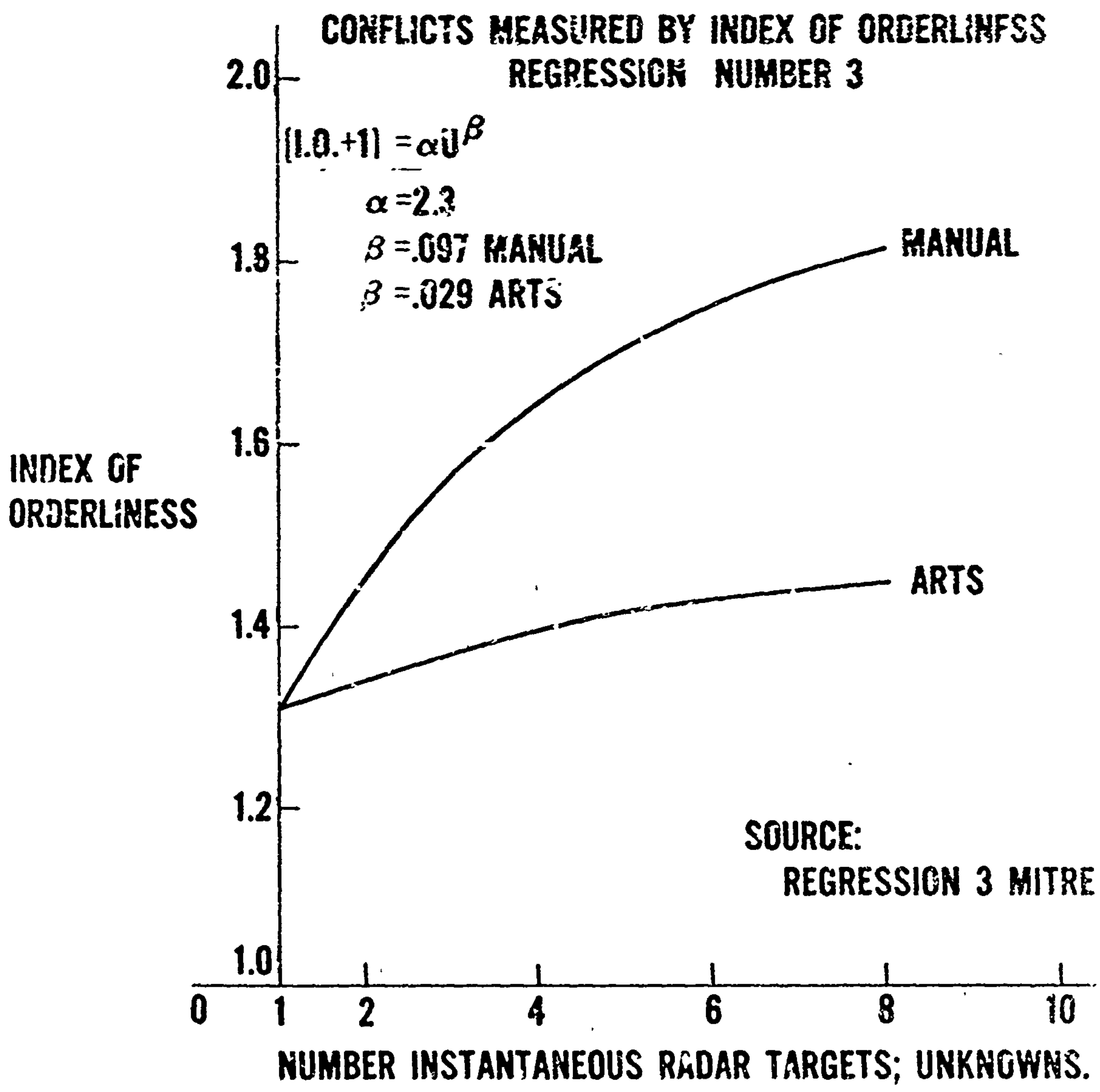
Regression #3

$$I.0 + 1 = \alpha \ \text{UNK}^{\beta}$$

| Version | Runs | $\alpha$ r.c. | $\beta$ r.c. | s.d. | Correlation Coefficient Unknown = Multiple |
|---|---|---|---|---|---|
| 1 | MAN - CER | 1.620 | .084 | .017 | .15 |
| | ARTS- CER | 1.818 | .023 | .007 | .10 |
| | MAN -NCER | 1.741 | .071 | .019 | .12 |
| | ARTS-NCER | 1.873 | .002 | .007 | .01 |
| 2 | MAN - CER | 2.892 | .135 | .025 | .16 |
| | ARTS- CER | 3.696 | .046 | .011 | .13 |
| | MAN -NCER | 3.104 | .114 | .026 | .13 |
| | ARTS-NCER | 3.722 | .003 | .011 | .01 |
| 3 | MAN - CER | 2.109 | .097 | .020 | .14 |
| | ARTS- CER | 2.530 | .029 | .009 | .10 |
| | MAN -NCER | 2.286 | .079 | .022 | .11 |
| | ARTS-NCER | 2.505 | .002 | .009 | .01 |

FIGURE A.1

## CONFLICTS VS. UNKNOWN RADAR COUNT
MANUAL–ARTS



difference in the rate of growth between ARTS and manual is statistically significant. Figure A-1 is a graphical presentation of this result. This result would have immense practical significance if the explanatory power of the regression equation were greater. This power is defined by the coefficient of correlation; the square of this coefficient represents the percent of the total variation in the data that is accounted for by the single variable: "unknown aircraft." This percent is low for regression numbers 1 and 2 (10 percent of the variance is explained), and even lower for regression number 3 (2-3 percent of the variance is accounted for). But, correlation analysis tells us that this percentage contribution by Mode C is highly significant statistically; the coefficient of correlation is five times as large as one would expect from a random sample of the size used in this analysis (1080 data points). But, the causes of conflicts, as revealed by the correlation analyses described above, are so varied that even though we can claim that, statistically speaking, the number of unknown aircraft explains the occurrence of conflicts to a significant degree, as a practical matter they do not explain very much (97 percent of the variation in conflict data remains unexplained).

## 4. TSC Statistical Analysis of Conflict Data

A parallel effort was undertaken by TSC to determine the isolated contribution made by the addition of Mode C capability. This effort was concerned primarily with an examination of those aircraft which came into conflict. Sophisticated mathematical techniques were employed to

fit Mode C and traffic activity variables to the actual record of conflicts: the index of orderliness was not used as a proxy.

In general, this effort produced results which were inconclusive. TSC did confirm, however, that "IFR traffic density is positively correlated with conflicts and percent Mode C (IFR) is negatively correlated with conflicts." It was found, for example, that "IFR traffic density accounts for the lion's share" of the conflicts, but "we have to leave unanswered the question as to whether a knowledge of the VFR traffic density contributes significantly to the probability of conflict when IFR traffic density is known." Further, TSC found that "no increased safety for Mode C aircraft was shown by these studies."

TSC concludes that, "our chief accomplishment was developing the analysis package, gaining experience in using it and discovering its weak points." The fault, however, was not in their method or lack of desire. It was simply a matter of trying to squeeze numbers beyond their usefulness. The study was not designed to provide conclusive information regarding what specific feature of ARTS III was most useful; Mode C, ground speed, alphanumeric identity, etc. It was intended only to compare the package of ARTS III automation with the manual system of air traffic control. The follow-on analyses revealed that a newly devised experiment, not further manipulation of the conflict data, is required to answer more specific questions concerning ARTS III.

In summary, while the inability to separate the contribution made by individual ARTS III features is a disappointing result of the total

follow-on analytical effort, there were a few modest gains nevertheless.

The rate of growth in conflicts as a function of traffic density, which was revealed in the MITRE analysis to have an exponential rate of growth of 1.0 for the manual system in regression 2 (record of severe violations), agrees with the analysis of near miss data shown in Figure 9. Both sets of data, obtained from independent sources, support the contention of a proportional, rather than a squared relation to traffic activity.

The data at a minimum do not refute the contention that Mode C is a significant contributor to the reduction in conflicts. They indicate that Mode C alone does not account for this reduction. Moreover, all regression analyses performed by The MITRE Corporation reveal that the rate of growth of conflicts with regard to traffic activity is less for the ARTS system than manual. This result, although statistically significant, indicates that a more precisely controlled experiment, designed for the single purpose of estimating traffic activity and Mode C effects is required before practical judgments can be made.

ACKNOWLEDGMENTS

A study which requires that the results of a physical experiment be joined with the apparatus of a cost/benefit analysis relies upon the contribution of many for its successful completion. There were the people who were part of the experiment; the FAA controllers who worked the simulator equipment, and those behind the scene at NAFEC who actually prepared and ran the experiment. The MITRE Corporation and the Transportation Systems Center provided their considerable analytical and software capability. And, almost without exception, the many offices and services within the FAA were most generous in their assistance. But, all this comes under the heading of people just doing their job, and while their contribution is gratefully acknowledged and appreciated, special mention is due those whose contribution went far beyond what was expected of them. Included in this category is Mr. Nathan Mantel of the National Cancer Institute in Bethesda who gave freely, with pun intended, of his immense store of statistical knowledge and experience. His assistance enabled an eager group of investigators, naive in the methods for the statistical design of experiments, to devise an experiment that worked. Special mention is due Professor Charles J. Stone of the University of California at Los Angeles whose profound analytical talents, provided as a consultant to the study, were necessary assets to the study. Then, too, the friendly guidance of Robert E. Swanson, a colleague from the Office of the Associate Administrator for Plans, merits special acknowledgment. His previous experience as an air traffic controller was consistently drawn upon, and the study could not have been completed without his frequent issuance of navigational directives and advisories on how to avoid bureaucratic turbulence.

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